ECHO

EFFICIENT COMPACT MODULAR THERMAL ENERGY STORAGE SYSTEM

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D2.3 – ECHO TSS agent-based simulation implementation final report

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Nomenclature

API – Application Programming Interface
COM – Component Object Model
CT – Transformer Substation
DHW – Domestic Hot Water
DSO – Distribution System Operator
ECHO – Efficient Compact Modular Thermal Energy Storage System
EPW – EnergyPlus Weather

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ESD – ECHO Scada Device
EUReCA – Energy Urban Resistance Capacitance Approach
GIS – Geographic Information System
GUI – Graphical User Interface
HP – Heat Pump
HVAC – Heating, Ventilation and Air Conditioning
H&C – Heating and cooling
RES – Renewable Energy Source
TES – Thermal Energy Storage
UBEM – Urban Building Energy Modelling

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1 Executive Summary

1.1 General objectives of ECHO TSS

The objective of this deliverable is the description, implementation, and its calibration through the data provided by the Crevillente pilot of the energy, electricity consumption, and economic flows accompanying the deployment of the ECHOTSS, an acronym for ECHO Transaction Simulation System, as a facilitator of options that implement and facilitate the flexibility of the demand.

ECHOTSS aims to simulate how a group of individual ECHO TES systems can operate through protocols of virtual automated transactions. It comprises several modules – describing the grid, the aggregated thermal demands, and the individual appliances through the individual control system which interoperates with the grid through a virtual aggregated capacity system called ECHO Cloud. The ECHO Cloud system acts as a "virtual high-capacity heat/cold store" that aggregates and coordinates the action of a potentially large number of individual ECHO appliances, thus multiplying the effect of the system. The overall objective of this deliverable is the description and implementation of the three main system modules and its calibration with real data provided by partner ENERCOOP. This will allow us to describe the effect on the demand side that the use of a certain number of centrally managed ECHO systems can provide and quantify the load shifting and electricity market aspects implied. In T2.4 this scheme will be applied to individual systems to provide a system-by-system agent-based simulation on a Geographical Information System basis. The layout and foundation of such agent-based analysis are laid in this deliverable by the interaction of the three modules that comprise the ECHOTSS tool.

1.2 Structure and modules of ECHO TSS

The conceptual map underlying ECHOTSS is shown in Figure 1. The physical actors operating in the system are the electricity trading companies, the distributors (DSOs) and the different individual actors operating ECHO systems connected to the electricity grid in the DSO's area of influence. The decision where individual systems should be installed, and other operational characteristics of the ECHO systems will be part of the more detailed simulations in Task 2.4. In each individual ECHO system, a program called ECHO Cloud Client connects the ECHO device to the ECHO Cloud aggregator system through two elements. The first is a smart contract whose purpose is to regulate the deliveries of electricity that occur through the ECHO Cloud system and within the framework of flexibility operations. The second element is the energy deliveries themselves, which are recorded in a component of ECHO Cloud that we call the Flexibility Aggregator.

Upstream of the ECHO Cloud operate the DSO and the electricity trading companies. The former, through the ECHO Climate and ECHO Grid programs (described below), can calculate their flexibility needs and communicate their offers to the ECHO Cloud web services module. Internally, ECHO Cloud automatically marries the flexibility offers with the storage space availability and thermal consumption of the ECHO Cloud of devices and communicates to the DSO which devices are available to consume power and in which order of priority. In turn, via the ECHO Client, it activates the smart contract that governs the process, triggers the switch on of the devices on that list and activates the premium the device will receive on its electricity bill for having taken up the DSO's flexibility offer.

The reward or discount is communicated to the supply company by the DSO, which will activate it on the monthly bill corresponding to the ECHO user, closing the communication circle of the ECHOTSS system. All metering operations are executed by the DSO, who in the Spanish system owns and operates the energy counters in each home.

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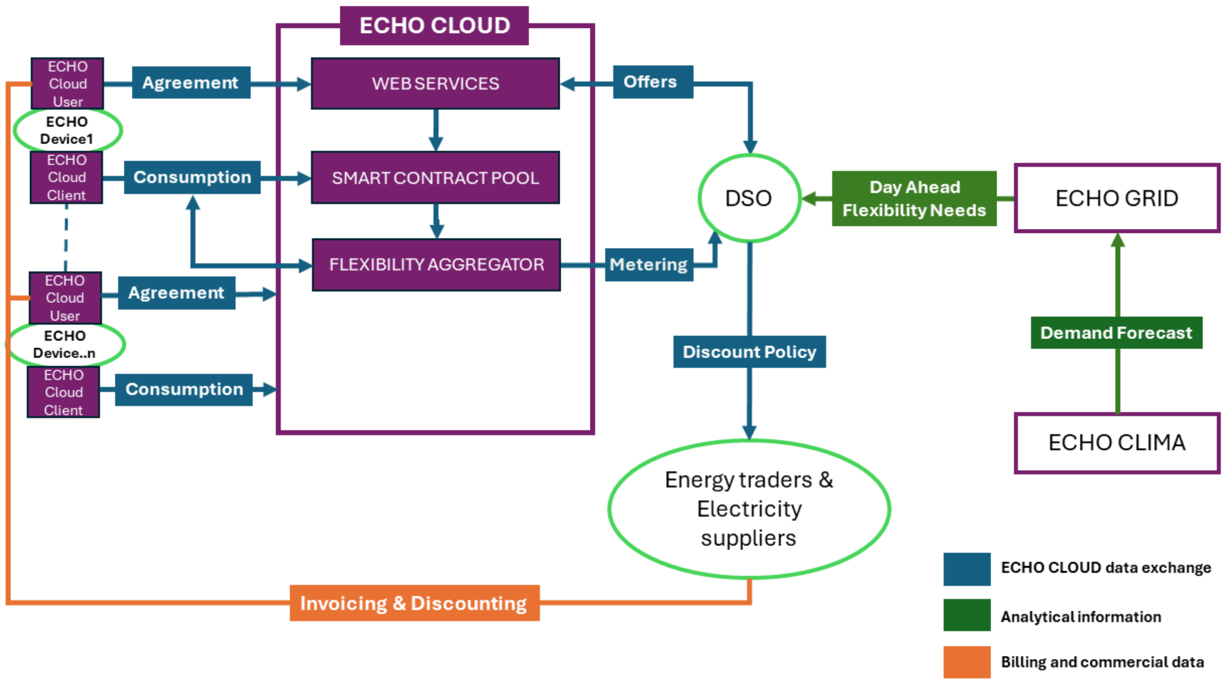

Figure 1 Conceptual map of ECHO TSS agent.

The three main ECHOTSS modules will be explained in the first three sections of this Deliverable:

1) In the section 2 (ECHO Clima: Thermal energy simulation.), the ECHO Clima tool, aimed at simulating thermal demand of large aggregates of buildings, will be introduced. Linked to a given demand structure in terms of the type and distribution of heat/cold consumer appliances, ECHO Clima allows the possibility, after careful calibration, to forecast the effect on electric consumption, de-aggregated by individual electric substations, of different ambient temperatures variations in the time frame of a 24h. The model structure, data acquisition and curation will be described along with its application to all buildings in our pilot city of Crevillente.

2) The following section 3 (The ECHO GRID module) reports on the ECHO GRID module, which thoroughly models the grid infrastructure and allows to predict grid operations at the scale of the sub-station infrastructure of a city. Once the ECHO Clima module outputs its predicted day-ahead electric consumption at the level of each of the sub-stations, ECHO GRID can model the flexibility needs from the point of view of the DSO to avoid possible shortages. The option to use flexibility to increase the amount of renewable electricity in off-peak conditions is another interesting aspect that can be analyzed using the ECHO GRID tool within ECHOTSS. A general description of the flexibility markets and their functioning under the Spanish market rules will be given resulting in a technical potential assessment of the feasibility of introducing ECHO as a tool to allow the increase of flexibility in the system.

3) Finally, the ECHO Cloud system is explained in detail in the section 4 called ECHO-CLOUD, describing the transactions between the participants in the ECHO Cloud and the market. The setup of a transparent concept of automatic smart contracting between market stakeholders within the ECHO Cloud environment is a key concept implemented herein via a conceptual design of a traceable automatic transaction system testable in the digital domain of flexible demand operations. The ECHO Cloud will enable small-scale ECHO tenants, to offer their storage capacity to a larger virtual store represented by the whole ECHO Cloud environment and to benefit from the discounts and prize

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advantages previously agreed on via Smarts Contracts which will be automatically launched under certain conditions. ECHO Cloud, which will be subsequently implemented inside the ECHO project pilots by partner GT in cooperation with partner IMP as part of WP5 activities.

The interconnected modules that comprise ECHOTSS will be applied, as data model and as feasibility testbench, to the information provided by ENERCOOP, as DSO, about the grid infrastructure and energy flows, household demand structure, market bidding characteristics, technical components, regulatory conditions and other critical input to evaluate the real possibilities for implementing demand flexibility policies in its grid.

The model will account for the influence of the most important climatic parameters on the heating and cooling demand to forecast the benefit that the ECHO thermal storage technology could provide in the scenario of changes in temperature and humidity conditions. In the ECHOTSS framework different flexible demand contracting schemes, adjusted to the legal requirements in each country, can be implemented and its effect on the ECHO Cloud behavior simulated. Hence, in the detailed simulations aimed at in Task 2.4, it will be possible to test different regulatory aspects in view of the different grid operator systems as well as the effect of economic incentive and bonuses.

In a final section, the information gathered will be used in a prospective way within different scenarios of future development of the grid such as change in climate conditions with an increase of extreme temperature events, accelerated degasification of the thermal demand, a faster transition to electric-based mobility and ECHO deployment scenarios. It is a first attempt to quantify and assess the potential impact that the inclusion of ECHO heat storage technologies together with a smart implementation of control can have to obtain a critical mass of demand that helps to shift the local energy mix towards the inclusion of larger amount of local RES electricity.

Altogether this work not only paves the way for the more detailed simulations to be carried out in Task 2.4, but already shall provide a general picture of how the ECHOTSS concept can aid strategically in the scenario of an energy transition towards RES and a more electrified HC system. It also shows how digitalization can contribute, via the ECHO Cloud concept, to win-win tradeoffs in the interest of all participants in the energy market: energy companies, policymakers, and, of course, the end-users.

2 ECHO Clima: Thermal energy simulation.

This section details and structures the ECHO Clima module, designed to identify the portion of a building's electricity demand curve attributable to climate control consumption. This module extends the EUReCA tool [2] (explained in the next section) to a city level, adapted to available information sources, and carefully curated within task 2.3 activities to validate its capabilities as a city-scale simulation system.

By integrating advanced thermal energy storage (TES) technologies with an AI-based control strategy, the ECHO Clima system can determine the hourly heating and cooling needs of buildings. For this purpose, ECHO Clima primarily uses meteorological data, user preferences, and information about the structure and distribution of thermal demand.

The ECHO Clima system's ability to forecast the electric demand is essential for simulating an efficient and reliable energy supply for buildings. By accurately modelling thermal energy requirements, the proposed method optimizes the integration of renewable energy sources and manages interactions with the power grid. This will result in significant cost savings and reduced greenhouse gas emissions because the system minimizes energy waste and maximizes the use of locally produced renewable energy. Additionally, ECHO Clima can be adapted to various building types and energy scenarios, making it a versatile solution for enhancing residential energy efficiency across different climate zones.

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The comparison of EUReCA output with other sources, such as energy certificates and national building energy demand report data, serves various crucial purposes. First, it ensures validation and accuracy and confirms that EUReCA's thermal energy simulation models represent real-life conditions. Cross-referencing EUReCA outputs with established data sources can identify discrepancies, thus validating model robustness and credibility. This comparison also aids in the improvement and optimization of simulation models by refining them to achieve better performance. Discrepancies between EUReCA outputs and other data allow adjustments in simulation parameters, thereby enhancing the predictive accuracy and optimizing energy efficiency measures and strategies.

2.1 EUReCA model structure

EUReCA (Energy Urban Resistance Capacitance Approach) is a Python-based Urban Building Energy Modelling (UBEM) platform designed to simulate the heating and cooling demands of urban districts. The tool's inputs include semantic geo-referenced data that describe **buildings' geometries**, **age classes**, **and end-uses**, which are linked to databases of building archetypes and operational schedules to simulate energy consumption accurately. Outputs from EUReCA provide detailed hourly and seasonal energy demands for heating and cooling, facilitating a comprehensive analysis of urban energy consumption. The tool's modular architecture allows for scalability from single buildings to entire city districts, making it an efficient and versatile option for urban energy evaluation.

To estimate the energy performance of the buildings, the model uses a simplified model, named 7R2C, based on ISO 13790 and VDI 6007 Standards (see Figure 2). This stands for a model with 7 resistors and 2 capacitors, representing the thermal dynamics within a building, where adiabatic and non-adiabatic building structures are analyzed separately aiming to achieve more accurate results for hourly loads.

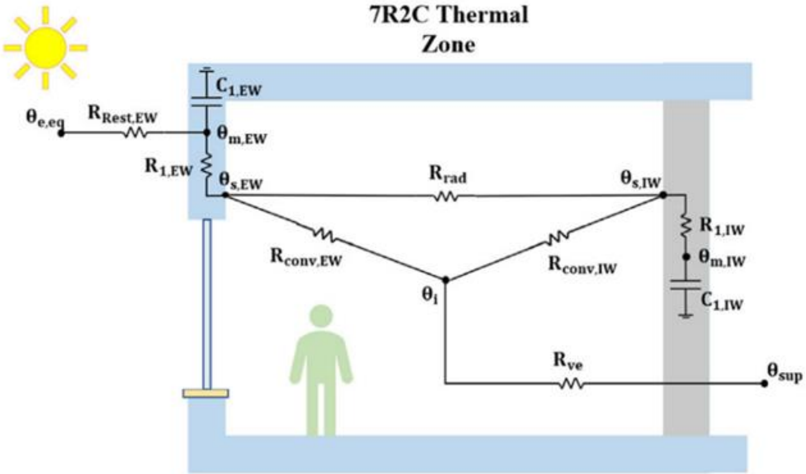

Figure 2 7R2C thermal network scheme. Data source: [2]

As a general idea, the input data needed to simulate cities, EUReCA requires the following information:

1. Geometric Data: The EUReCA platform processes buildings' geometries using geo-referenced semantic models such as CityJSON and 2D GeoJSON models derived from GIS Shapefiles. Figure 3 represents the operation scheme of the geometry handling in EUReCA. This can be typically based on the **Cadastral GIS information**.
2. Building Envelope Archetype: This includes structures' thermal parameters corresponding to different age classes. This is described by the **Envelope file** (next section).
3. Operational Schedules and Gains: Data for different end-uses is provided from an integrated database. This is described by the **Schedule file** (next section).

4. Meteorological Data: External ambient conditions are obtained from EPW weather data. This is described by a **Weather file** (next section).
5. Internal Heat Gains: Includes both radiant and convective heat gains distributed to air nodes and surface nodes. This is described by a **Weather file** (next section).
6. Solar Gains: The solar heat gains calculation considers the angle of incidence of direct solar radiation and characteristic curves for different glazing types. This is described by a **Weather file** (next section).

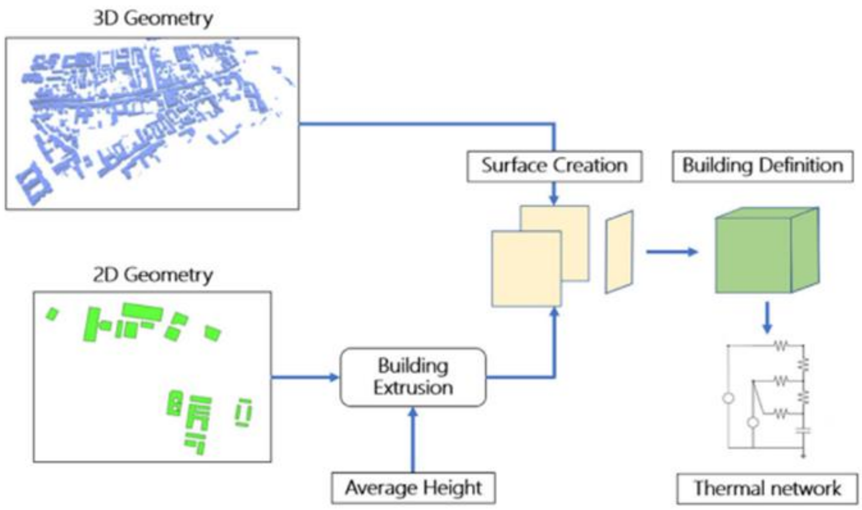

Figure 3 Schematic overview of the geometry handling in EUReCA. Data source: [2]

Once EUReCA simulations are run, the output files provided by EUREcA are the following ones:

1. A file with the hourly aggregated consumptions of the city simulated for wood, gas, electricity, and oil, as well as thermal and domestic hot water demand.
2. A file for each building of the city with the thermal demand, the consumption of the heating system, the consumption of the cooling system and the thermal zone sensible and latent load among other information.
3. A summary file with the consumption for each month, thermal demand, and data like the net area or volume for each building of the simulated city.

2.2 EUReCA Model input data information

To effectively run the EUReCA model, input data must be converted into a GeoJSON format, which facilitates geospatial analysis and visualization. In this section, the input data, its translation into GeoJSON file city model, and the main databases considered are described.

2.2.1 Envelope file

The envelope file is a critical component of the EUReCA model, essential for accurately simulating a building's energy performance. It contains comprehensive information about the building's physical characteristics, particularly those that impact energy efficiency. Specifically, the envelope file serves as a repository for data about the building's external structure, encompassing the thermophysical properties of walls, roofs, windows, and other elements that interact with the external environment.

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To ensure precision, the buildings are classified by their age, which dictates the specific materials and U-values for all structural elements. This classification is crucial because the construction standards and materials used have evolved significantly over the years, influencing the thermal performance of buildings.

Archetypes have been defined according to the year of construction, as illustrated in Table 1, which lists these archetypes. These archetypes are based on the various construction regulations in Spain that were in effect over different periods. Each regulation period defined an archetype according to the minimum construction standards mandated at that time, including specifications for the thermal envelope and closures, resulting in a specific thermal transmittance value (U-value).

Table 1 Definition of different archetypes with their thermal transmittance value (U-value)

Year of Construction	Current Regulation[1]	Roof	GroundFloor	IntCeiling	ExtWall	IntWall	Window
> 2019	CTE 2019	70	71	72	73	74	75
2013-2019	CTE 2013	76	77	78	79	80	81
1979-2012	NBE 1979	82	83	84	85	86	87
1960-1978	MV 1960	88	89	90	91	92	93
1937-1959	MOP 1937	94	95	96	97	98	99
1901-1936	MO 1901	100	101	102	103	104	105
< 1901	Pre-MO 1901	106	107	108	109	110	111

Therefore, a list of archetypes was defined based on the construction year intervals of the buildings. For the thermal simulations, a building file was created by obtaining the construction years from the GIS information of the cadastre. This approach allows for a detailed and accurate representation of the building stock, ensuring that the thermal simulations reflect the actual energy performance of buildings constructed under different regulatory frameworks.

The envelope file is composed of several sheets, each containing distinct information. The first sheet, titled "Envelopes," assigns IDs to various construction components of the building (such as the roof, ground floor, interior ceiling, exterior and interior walls, and windows) based on the year of construction.

In the "Constructions" section (Figure 53 in Annex), a U-value is assigned for each of the IDs defined in the previous section. The "Materials" section sets the construction materials and their properties, including their thickness, conductivity, density, specific heat, thermal absorptance, and thermal resistance. This section was not used in the EUReCA simulations due to a lack of data relating to the building materials of the city under study.

Finally, in the "Windows" section (Figure 53 in Annex), windows properties like the U-value or the solar heat gain coefficient are defined.

2.2.2 Weather file

An EPW (EnergyPlus Weather) file is a standard weather format. The first headers of a weather file define basic location information such as longitude, latitude, time zone, elevation, annual design conditions, monthly average ground temperatures, typical and extreme periods, holidays/daylight saving periods, and data periods included. Additionally, a weather file may contain several data periods composed by several

[1] **CTE 2019**: Technical Building Code of 2019, setting modern construction standards.
CTE 2013: Technical Building Code of 2013, outlining previous construction standards.
NBE 1979: Basic Building Standards of 1979, specifying thermal insulation requirements.
MV 1960: Housing Ministerial Order of 1960, defining building materials and methods.
MOP 1937: Public Works Ministerial Order of 1937, establishing early building regulations.
MO 1901: Ministerial Order of 1901, detailing construction practices of the early 20th century.
Pre-MO 1901: Regulations prior to the 1901 Ministerial Order, covering historical building methods.

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fields such as time, dry bulb temperature, relative humidity, wind direction and speed, and other meteorological and radiation fields.

For the time period from 28/08/2022 to 27/08/2023, two weather files have been prepared to enable EUReCA simulation using the corresponding electrical consumption data from ENERCOOP. One will contain data for the year 2022 and the other for the year 2023.The weather file for Alicante can be found in the EnergyPlus documentation and serves as the basis for both EPWs. However, this file contains mixed data from several years, so to make the two files as accurate as possible, a historical weather API was used to obtain more specific data for the city of Crevillente and for the specified years.

The weather information collected from the API, includes the dry bulb temperature, the dew point temperature, relative humidity, wind direction, and speed, surface pressure, cloud cover total and high, and several solar radiation variables.

2.2.3 Schedule file

A variety of schedules including those related to occupancies, appliances, temperatures, and humidity setpoints are established by the intended end use of the building. In the simulations, the following end users have been considered: residential, office, industrial, services, and commercial buildings, and the schedules have been defined using the values of the Spanish norm UNE-EN 16798-1 (see from Table 10 to Table 13 in Annex).

2.2.4 Input data to city model translation

EUReCA can handle two typologies of JSON city models. The recommended methodology consists of importing buildings' geometries via semantic CityJSON files along with 2D shapefiles encoded in GeoJSON format, aimed at building the city. The GeoJSON model was chosen for running the simulations due to its simplicity and compatibility with the GIS environment. Therefore, the input data mentioned above needs to be processed and translated into the GeoJSON fields to build the city model. The required attributes for the GeoJSON file are (see Figure 4):

- **"Envelope":** it refers to the year of construction and must be defined as an archetype in the envelope file.
- **"Floors":** number of floors as a float.
- **"areaValue":** the total surface of the building.
- **"Height":** the height of the building as a float.
- **"Heating load":** the name of the heating system installed in the building.
- **"Cooling load":** the name of the cooling system installed in the building.
- **"End Use":** is the end use of the building and must be defined as an archetype in the schedule file.
- **"id":** an identifier number for each building. It must be an integer.
- **"Name":** a name for each building. It can be any type of value.

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Envelope model
Cadastral data
Energy system

	Envelope	Floors	areaValue	Height	Heating Lo	Cooling Lo	End Use	C_plant	id	Name
1	1937-1959	2	88	5	IdealLoad	IdealLoad	Residential	IdealLoad	7787	7787
2	1960-1978	4	69	10	IdealLoad	IdealLoad	Residential	IdealLoad	8027	8027
3	1979-2012	5	244	13	IdealLoad	IdealLoad	Residential	IdealLoad	7278	7278
4	1937-1959	4	77	10	IdealLoad	IdealLoad	Residential	IdealLoad	7353	7353
5	1979-2012	5	602	13	IdealLoad	IdealLoad	Residential	IdealLoad	7688	7688
6	1937-1959	4	65	10	IdealLoad	IdealLoad	Residential	IdealLoad	7725	7725
7	1937-1959	5	103	13	IdealLoad	IdealLoad	Residential	IdealLoad	7788	7788
8	1979-2012	2	66	5	IdealLoad	IdealLoad	Residential	IdealLoad	8044	8044
9	1979-2012	6	866	15	IdealLoad	IdealLoad	Residential	IdealLoad	7285	7285

Figure 4 Overview of a GeoJSON file example to build the city model.

The main databases to construct the city model are the Cadastral Service and the building code. As for the former, data regarding the number of floors, height, year of construction, and surface are provided in GIS format. The latter offers information concerning the U-values for the walls, roof, and ceilings connected to the year of construction.

2.2.5 Configuration file

This file contains the simulation parameters and solar radiation settings which are not included in the weather file. The simulation settings included in this file are the simulation start and final date, the simulation reference year, the number of time steps per hour, and the start and end of the heating and cooling season. As for the solar radiation settings here included, they are the height subdivisions, azimuth subdivisions, and urban shading tolerances. Figure 5 shows an example of the simulation file.

```
{
  "DEFAULT": {},
  "model": {
    "name": "example_model"
  },
  "simulation settings": {
    "time steps per hour": "1",
    "simulation reference year" : "2022",
    "start date": "01-01 00:00",
    "final date": "12-31 23:00",
    "heating season start": "10-01 00:00",
    "heating season end": "04-30 00:00",
    "cooling season start": "05-01 00:00",
    "cooling season end": "09-30 00:00"
  },
  "solar radiation settings": {
    "do solar radiation calculation": "True",
    "height subdivisions": "4",
    "azimuth subdivisions": "8",
    "urban shading tolerances": "80.,100.,80."
  }
}
```

```
{
  "DEFAULT": {},
  "model": {
    "name": "example_model"
  },
  "simulation settings": {
    "time steps per hour": "1",
    "simulation reference year" : "2023",
    "start date": "01-01 00:00",
    "final date": "12-31 23:00",
    "heating season start": "10-01 00:00",
    "heating season end": "04-30 00:00",
    "cooling season start": "05-01 00:00",
    "cooling season end": "09-30 00:00"
  },
  "solar radiation settings": {
    "do solar radiation calculation": "True",
    "height subdivisions": "4",
    "azimuth subdivisions": "8",
    "urban shading tolerances": "80.,100.,80."
  }
}
```

Figure 5 Simulation and solar radiation settings in the configuration file.

2.3 Application of the EUReCA model to the city of Crevillente

2.3.1 Data model, thermal and electricity demand

Crevillente (Figure 6) is a Spanish municipality and town in Alicante Province, located south of the Valencian Community. The total surface of the municipality covers 104 Km^2 and it is considered a medium size municipality accounting for 28,600 inhabitants. The climate of this region is typical of Mediterranean regions,

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with hot and humid summers and long, cold, and windy winters. The average temperature of Crevillente in 2023 was 18.8 ºC July being the hottest month with temperatures around 28 ºC and the coldest month, February with an average temperature of 10.2 ºC. In Figure 7, the air temperature and relative humidity of Crevillente for the year 2023 are displayed.

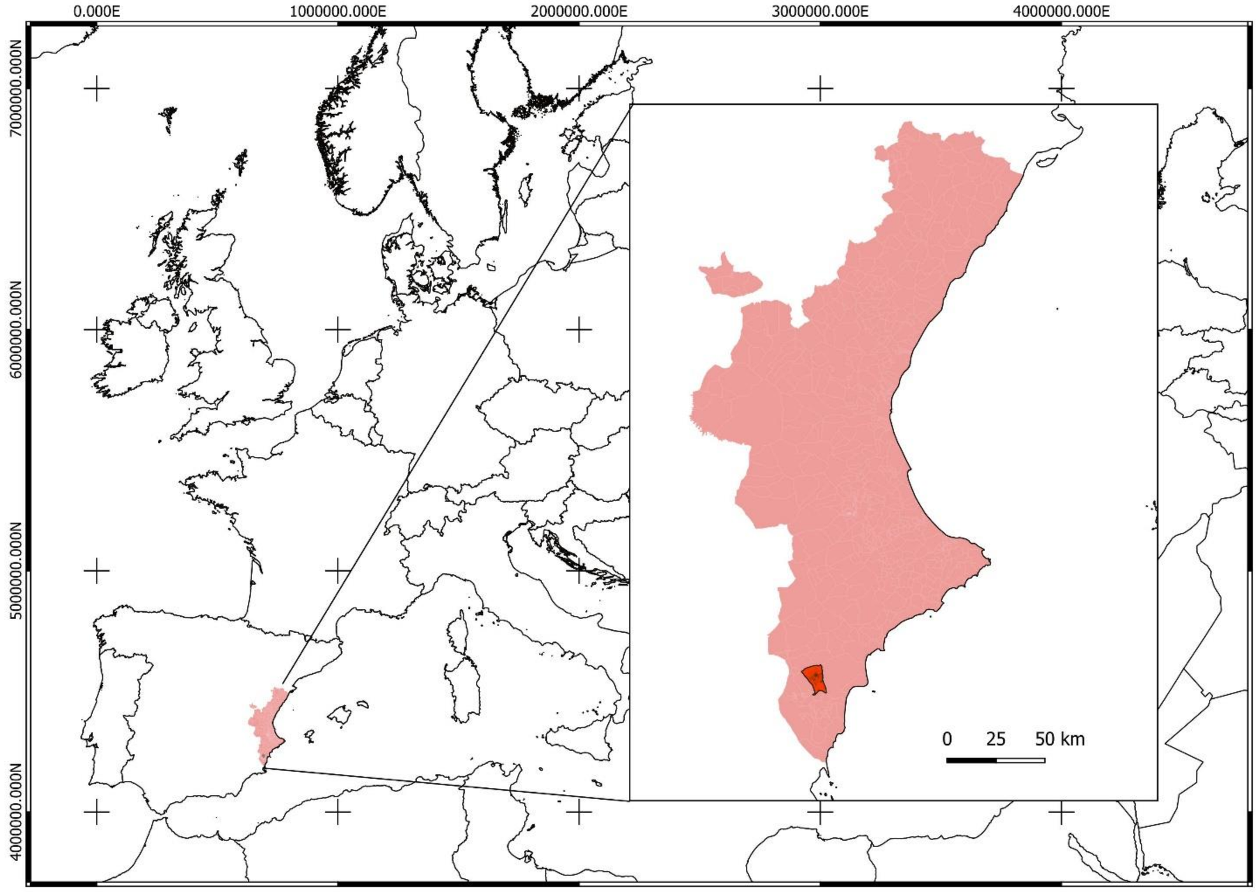

Figure 6 Location of Crevillente on a Europe map.

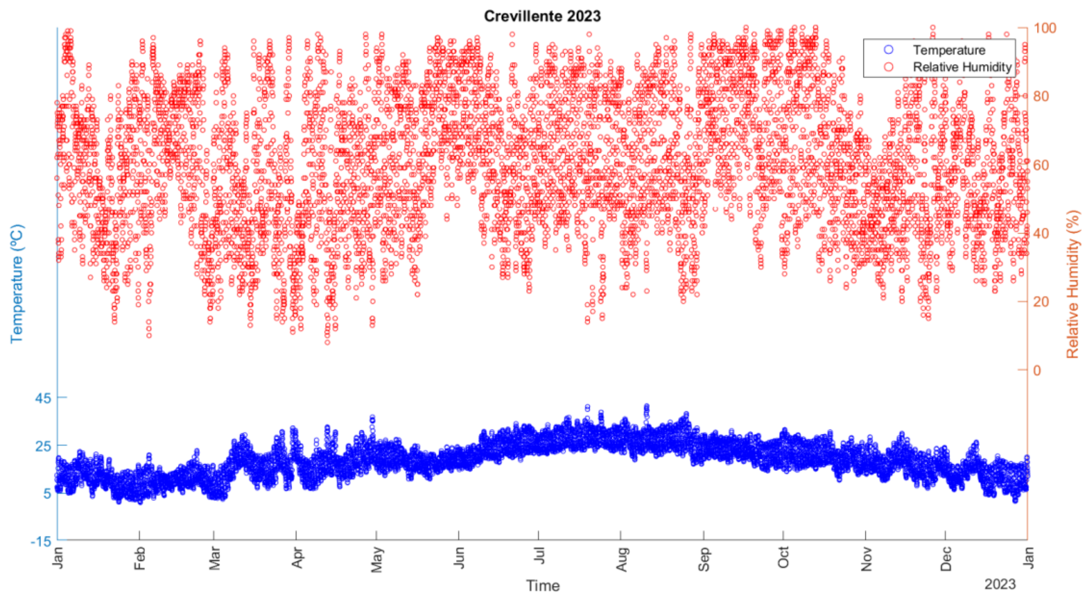

Figure 7 Air temperature and relative humidity for the city of Crevillente.

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From the comprehensive information provided, thoughtfully curated and analyzed we have constructed maps such as those shown from Figure 8 to Figure 13 which allow a complete characterization of the thermal demands and their relationship with electricity consumption in the case of Crevillente.

These maps not only allow us to observe the different intensities and demands depending on the urban areas of Crevillente and their building typologies but also to analyze the relationship between the thermal demand simulated by EUReCA and its real impact on electricity consumption through the relationship between the buildings and the consumption of their associated substations. In the following, we will go deeper into this analysis by studying a limited set of electric transformer stations that allow us to obtain representative conclusions.

Within ECHO we characterized the different population centers, such as the El Realengo zone or the urban core of the city itself. Electricity is supplied to these buildings by different electric transformer stations distributed throughout the city, and partner ENERCOOP provided the necessary information. This information includes the center to which each building belongs and the electricity consumption of each building. On the other side, building location, their geometric, and end-use typology were collected from the Cadastral Service in GIS format.

An important and exhaustive work to match the addresses provided by ENERCOOP and those obtained from the cadastre was undertaken to use the GIS environment and obtain the maps shown below. The main difficulties identified were mainly due to addresses with different formats in the cadastre and the data provided by ENERCOOP or street names that had been completely modified.

Figure 8 presents a detailed map of Crevillente municipality, highlighting different building typologies and the locations of electric substations. The buildings are categorized into several types: commercial (green), industrial (blue), office (orange), residential (grey), and services (red). In total, the study case accounts for 3,651 buildings, and from them, 30 buildings belong to the Services sector, 43 are Commercial, 14 are Offices, 107 are Industrial buildings, and the rest, 3,457 are Residential buildings. At the bottom part of Figure 8 and the following, a small area can be seen with a different scale in the map, representing the El Realengo area, located 8 km South of Crevillente city center. It was highlighted and included in the maps due to their buildings being eminently residential, with a low penetration of the other building uses, which makes it an interesting area case within the study case.

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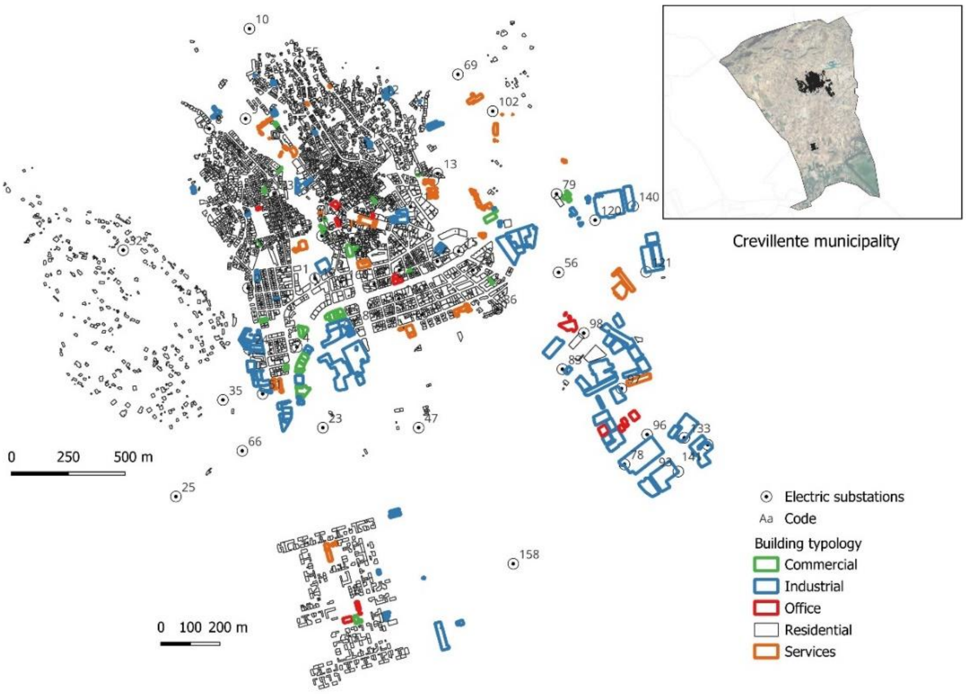

Figure 8 Crevillente study case making a difference among the end-use building typologies.

Figure 9 provides a comprehensive view of the electrical infrastructure in Crevillente municipality. It shows the distribution of the 56 electric substations and the buildings they serve, illustrating a well-planned and organized electrical grid. They provide service to a different number of buildings varying from 352 buildings for substation 61 to only 1 for substation 60. Every building connected to the same electric substation is shown in the same color. Certain substations, such as numbers 1, 2, 3, and 4, cover densely built-up areas, suggesting they serve high-density residential or commercial zones. Other substations, like numbers 17 and 18, cover less dense areas, indicating lower residential or industrial zones.

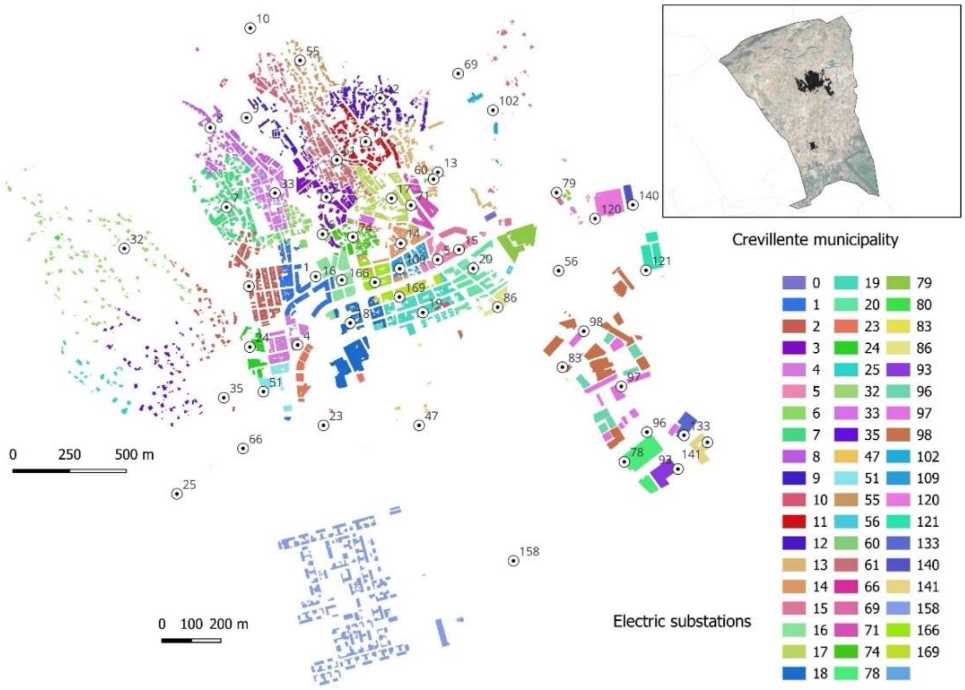

Figure 9 Crevillente study case showing the Electric Substations and the buildings connected.

Figure 10 shows the thermal demand over time for two different transformation centers (CT32 and CT158) with varying building typologies.

- CT32 (yellow) typically has the lowest thermal demand peaks among the three. This center is composed entirely of residential buildings (86 buildings). It shows the lowest variation and lowest peaks, aligning with the typical lower demand patterns of residential areas.
- CT158 (blue) includes a mix of residential (89 buildings), industrial (5), office (3), service (1), and commercial buildings (1). It generally exhibits the highest thermal demand peaks. It consistently has higher peaks and variability, which indicates a more diverse and intensive usage pattern, likely due to non-residential buildings requiring more heating or cooling.

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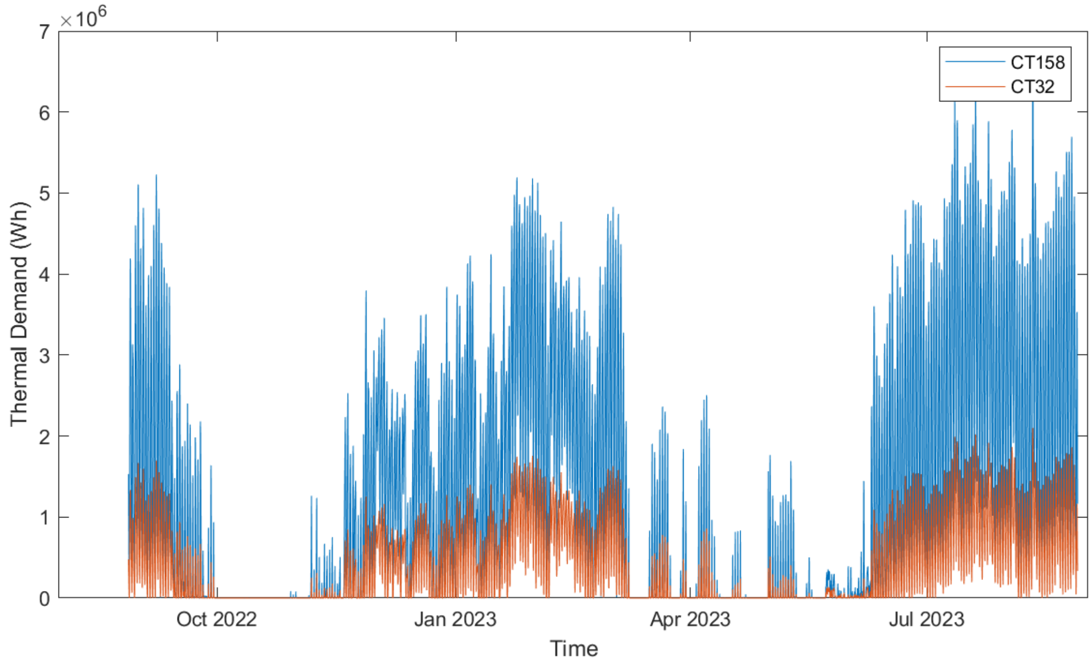

Figure 10 Thermal demand for the transformation centers 32 and 158.

The building typology significantly affects the thermal demand patterns. Mixed-use areas with industrial, commercial, and service buildings (such as CT158) have higher and more variable thermal demands compared to predominantly residential areas (such as CT32).

As for the impact of Building Typology, the high peaks in CT158 can be attributed to the presence of industrial, office, service, and commercial buildings, which typically have higher thermal demand compared to purely residential areas. CT32is primarily residential andshow lower overall demand.

There are clear seasonal patterns in thermal demand across all transformation centers. Higher demands are observed during winter (e.g., December to February), likely due to heating requirements. Lower demands are seen during the warmer months (e.g., April to October).

Figure 11 and Figure 12 shows the annual heating and cooling demand per building. The average heating and cooling demand are quite similar, being around 25 MWh in both cases. However, the standard deviation for cooling demand is notably higher (40 MWh) compared to heating demand (32 MWh), indicating that cooling demand varies more widely across different buildings. The minimum values for both heating and cooling demands are also very close, around 0.35 to 0.45 MWh respectively, but the maximum values show a significant difference, with cooling demand peaking at over 1.12 TWh compared to the maximum heating demand of approximately 913 MWh. Figure 13 shows the total demand.

When examining the heating and cooling demands by different building end uses, industrial and services sectors stand out with significantly higher demands. The analysis also shows that the industrial and services sectors have significantly higher energy demands, particularly for cooling, due to the nature of their activities. In contrast, residential and commercial buildings have lower and more balanced heating and cooling demands, reflecting their smaller scale and less intensive energy use.

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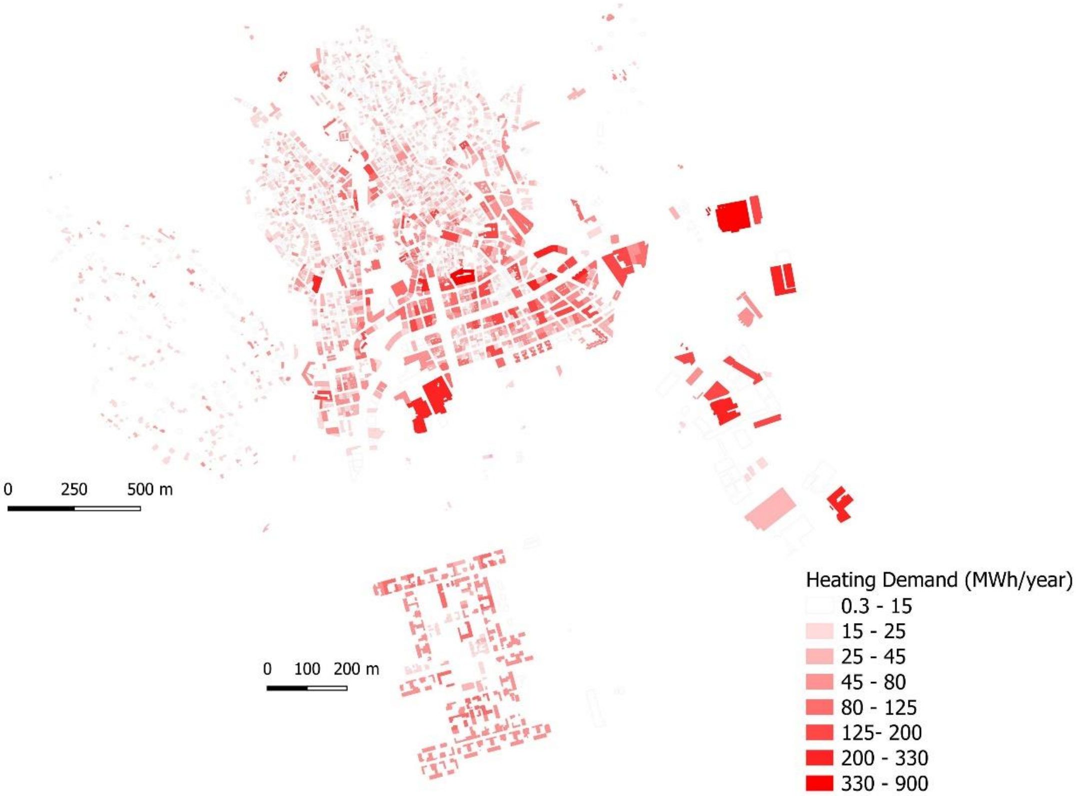

Figure 11 Crevillente study case annual heating demand.

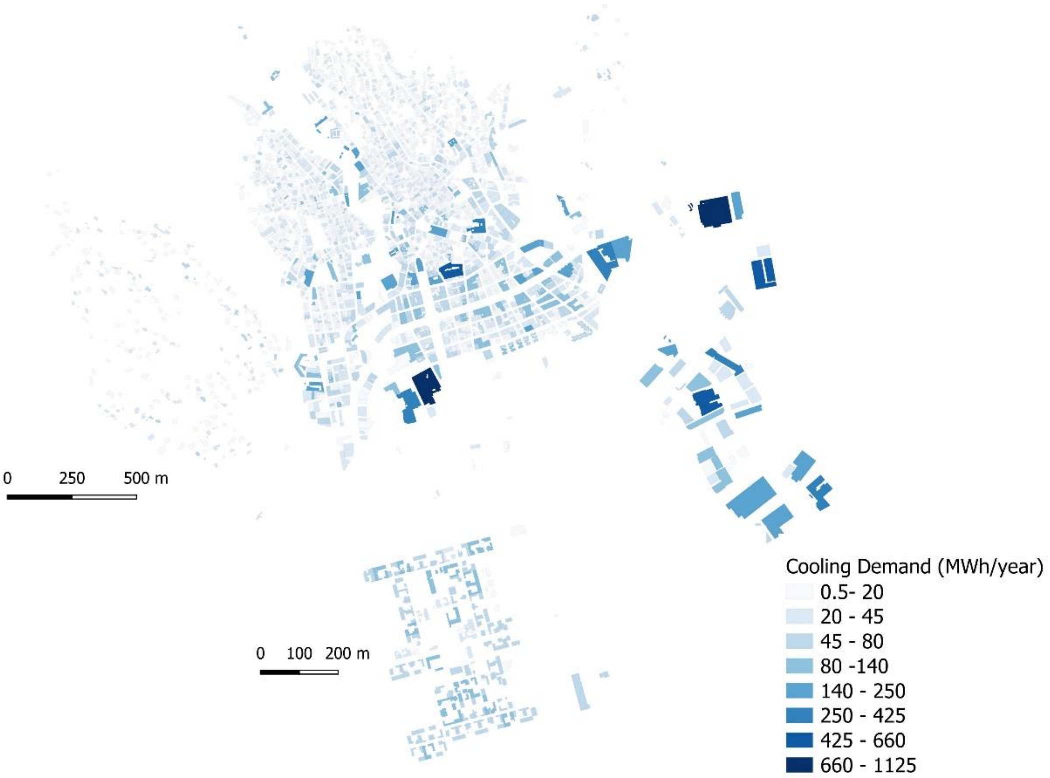

Figure 12 Crevillente study case annual cooling demand.

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Finally, to understand how heating and cooling demands vary by electric substation and by end use of the buildings, the analysis indicates that the energy demands for heating and cooling vary significantly based on both aspects: Industrial and services sectors exhibit the highest demands, particularly for cooling, due to their operational nature; on the other side, residential and commercial sectors, while still significant, generally have lower demands.

Figure 13 Crevillente study case total (Heating+Cooling) demand.

2.3.2 Relationship between simulated thermal demands and electricity consumption in Crevillente

Demand and electric consumption in CT158

As a representative example of both consumption and demand data, in Figure 14 two graphs are presented: the first graph compares the demand of all buildings of the simulated CT and the air temperature, and the second one compares the electrical consumption of the CT and air temperature. During peak hours, both thermal demand and consumption tend to increase (see Figure 15). This tendency is also influenced by the outside temperature. In winter and summer, when the temperature varies, the demand for heating or cooling the building increases, resulting in higher electricity consumption. This behavior is logical and provides evidence that the values obtained from the simulation are accurate representations of reality.

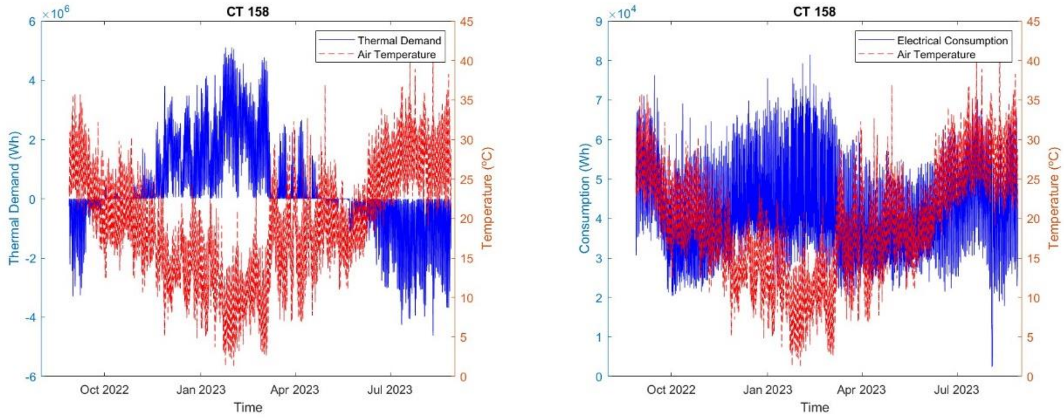

Figure 14 Thermal demand and electrical consumption comparison with air temperature for the transformation center 158.

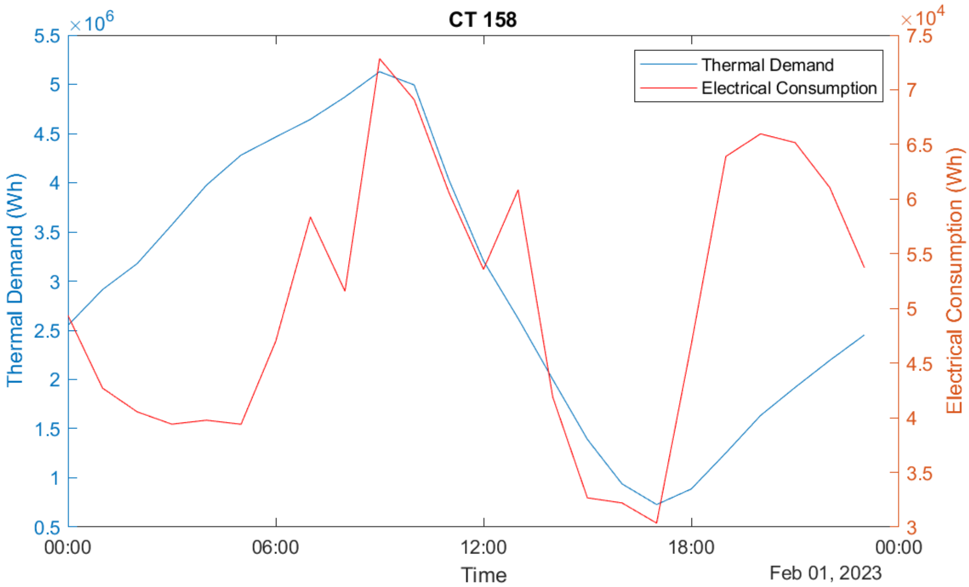

Figure 15 Thermal demand and electrical consumption for the transformation center 158 on 1 February 2023.

In the previous figure, the cooling demand has been represented by negative values to differentiate more easily between heating and cooling seasons. Although there are periods where both thermal demand and electrical consumption increase or decrease together, the overall patterns suggest that thermal demand is more consistent with heating needs, which peak in the evening. Electrical consumption, on the other hand, may be more influenced by specific activities and operational schedules within the buildings in CT158.

Neutral temperature

To characterize the influence of thermal demands on electricity consumption, we have pursued an indirect route by expressing both the hourly demands simulated by means of EUReCA and the values measured at each electrical substation as a function of a common factor that we have determined mathematically as the temperature difference of the measured hourly outdoor temperature concerning a reference that we call "neutral temperature", which represents the hourly outdoor temperature, T_0 at which the cooling or heating demands are closest to zero.

We can assume that the thermal component of the electrical consumption and the EUReCA simulated thermal demands will fundamentally depend on this difference. We can determine the value of this temperature as the temperature value that maximizes the correlation between the temperature difference

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(as a function of T_0, a priori unknown) and the thermal demand calculated by EUReCA. Correlation is typically used to measure covariation[2], i.e., whether one variable tends to vary similarly to another and ranges between *-1* and *+1*. In this case we find the correlation between the two vectors given by $\Delta T(t) = (T(t) - T_0)$ and $E_{CT,N}(t)$, representing respectively the said temperature difference and the hourly demand calculated by EUReCA for the substation *N* to which data are referred.

The graph shown below plots the resulting correlation as a function of T_0, indicating clearly that the neutral temperature that best represents the results of EUReCA is around 19ºC in the case of CT19, 21ºC in the case of CT158 and 24ºC in the case of CT32.

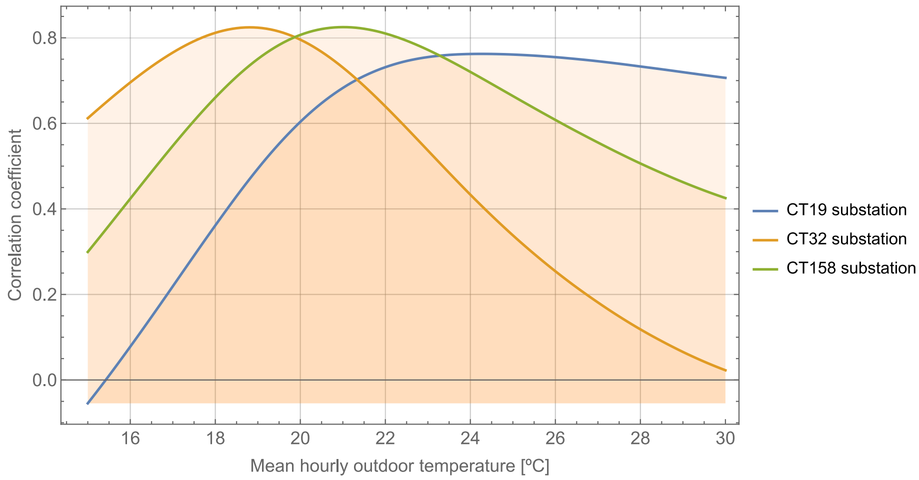

Figure 16 Correlation between EUReCA based heat and cold demand prediction and hourly differences between the outdoor temperatures and the neutral temperatures shown as X axis in the graph.

The information obtained by means of this analysis is not only useful to construct more accurate predictions for heating and cooling electricity consumptions, but also correlates with the structure and characteristics of the building stock connected to these demands. In the case of CT19 we observe that the demand is rather insensitive to low temperatures. Cooling demand starts to be relevant at comparatively higher outdoor temperatures, but from then on it maintains a relatively high correlation with the outdoor temperature. In the district covered by CT158 we observe the best match between officially recognized comfort temperature of about 22ºC and thermal demands, possibly determined by the industrial and commercial activities in some of the buildings. CT32 exhibits a quite insensitive behavior towards higher temperatures and the lowest transition between heating and cooling demands at 19ºC. Hence, although the demand turns to cooling at a quite low temperature, it shows a quite insensitive relationship with the observed outdoor temperatures, which correlates with lower electricity consumption in this group of buildings.

2.3.3 Thermal results analysis

To represent the effect of outdoor temperature differences concerning neutral temperature Figure 17 was produced, to show – in the form of Box-Whiskers diagrams - the variability of the demand and the typical demand as a function of the different $\Delta T(t)'s$. In red, the outliers are shown. Data refer to CT158.

[2] Strictly defined, correlation of two *v* and *w* vectors is given by $\rho_{vw} = \sigma_{vw}/(\sigma_v \sigma_w)$ with $\sigma_{v\,w}$ being the covariance between both and and σ_v and σ_w their respective standard deviations.

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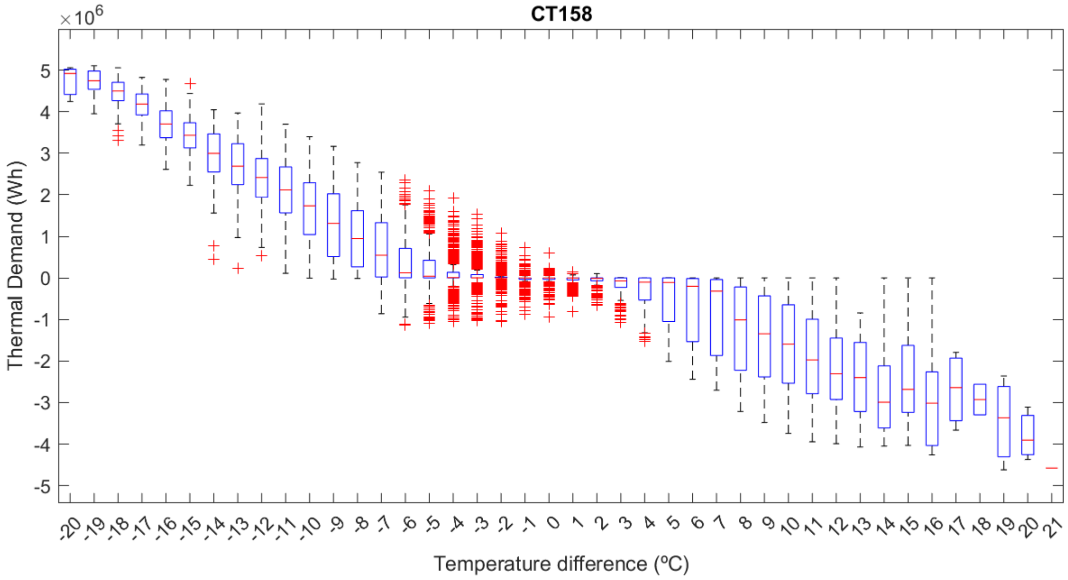

Figure 17 Variation of the thermal demand as a function of hourly mean temperature difference with respect to the neutral temperature.

The above graph shows the clear correlation between outdoor temperature difference and heat and cold demand. Specifically in cooling dominated conditions (positive temperature difference) there is a considerable variability as shown in from the height of the bars, therefore it is important to consider additional factors that affect the demand. One important factor is the time slot in which the outdoor temperature is reached, as Figure 17 shows. For this plot, three time slots were defined to categorize the outdoor temperature difference data: the first runs from 12 a.m. to 6 a.m., the second extends from 7 a.m. to 7 p.m. and lastly, the third is from 8 p.m. to 11 p.m. As the graph shows, the time slot in which the cooling demand is more sensitive to outdoor temperature conditions is the 8 p.m. to 11 p.m slot. On the other hand, heating demands are more important during the second slot, from 7 a.m. to 7 p.m.

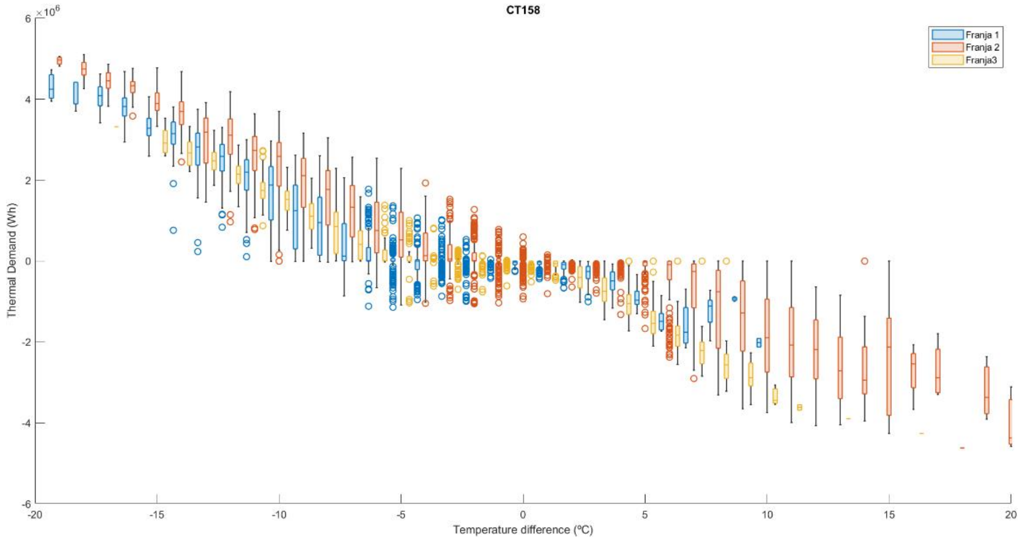

Figure 18 Variation of the thermal demand as a function of temperature difference and time slots

2.3.4 Correlation between outdoor temperatures and actual electric consumption

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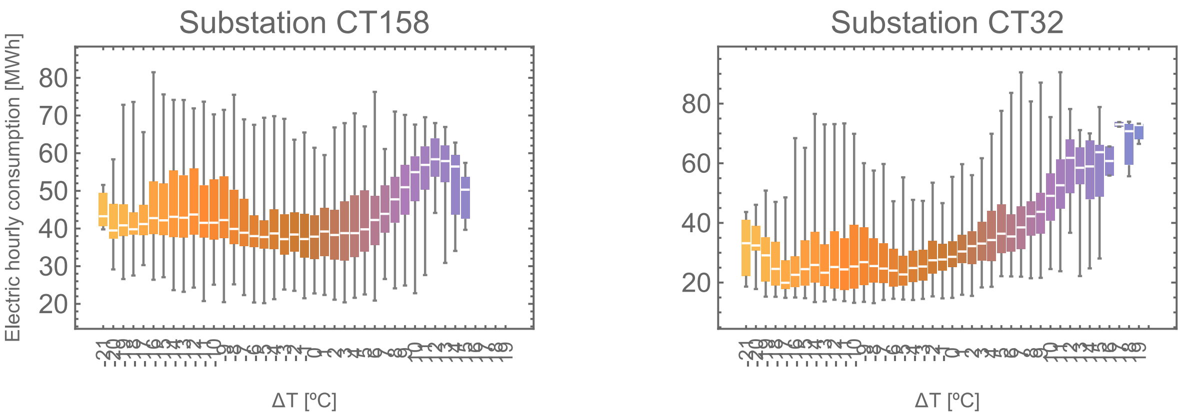

Figure 19 Variation of the electric demand as a function of temperature difference in centers CT 158 and CT 32.

Once the factors that affect the heating and cooling demand are clarified it is easier to characterize the relationship between actual electric consumption and outdoor temperature conditions. As the above plot, Figure 19, depicts, this dependence is neither linear nor can it be directly deduced from the demand curves discussed above, but is mediated by other factors such as, fundamentally, the electrification of thermal generation, the efficiency of generation equipment, specific use patterns or the alternative of other energy sources, particularly gas in the case of heating. The above graph is therefore especially significant as two factors stand out:

1. There is a considerable sensitivity of electricity consumption to increases from the neutral temperature. Thus, differences of +14ºC lead to overconsumption of 54% in the case of CT158 and 110% in the case of CT32.

2. Electricity consumption during heating dominated climate conditions is much less sensitive to outdoor temperatures than the corresponding consumption in cooling dominated conditions. This fact is linked to the existence of a replacement fuel such as fossil gas, with a strong penetration in Crevillente, as in much of Spain as well as Southern Europe.

The interconversion of thermal demand conditions simulated by EUReCA to electricity consumption requires thus careful consideration of such factors.

Following this perspective, the next section analyses the factors influencing such reality as, for example, the prevalence of different heating and cooling technologies and sources in a town like Crevillente. It should be noted that it has been impossible to obtain information directly from the dwellings analysed, so we have resorted to bibliographic and statistical sources which, as will be shown, are scarce and not very up to date.

2.4 Electric consumption validation and predictive models

We consider two types of predictive frameworks. On the one hand, short term predictions (one day to one week ahead) that the ECHO CLIMATE module communicates to ECHO GRID for the planning of flexibility measures, on the other hand, longer term simulations that aim to represent changes in energy consumption patterns due to major changes in the demand configuration such as a higher penetration rate of electrification to meet thermal demands or other structural factors.

For short-term predictions, algorithms based on machine learning tools are suitable, as they have a high predictive capability.

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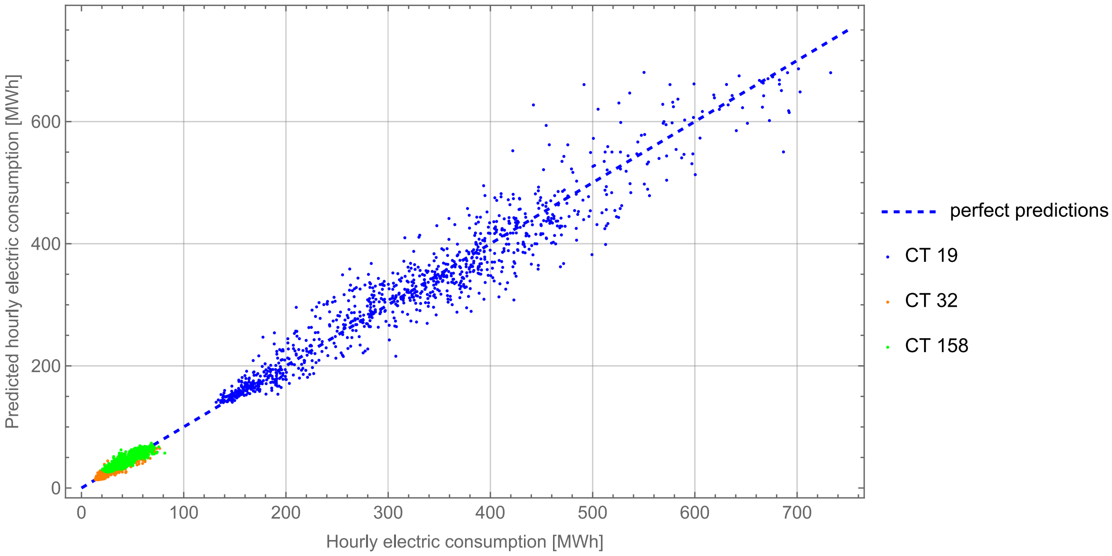

Figure 20 Predicted vs. real electric demand in centers CT 19, 32 and 158 based on three Neural Networks-based predictor functions.

As an example, the above figure shows the correlation between predicted and measured electric consumption in the three substations that have been used as test bench for ECHO Clima. The predictive models are based Neural Networks with a 6-layers architecture that contains temperature data, information linked to the seasonality and festivity of a given date, as well as the timing of each sample. A further network layer contains information on the current electricity prices in the electricity pool for the day in question. In a more refined version of these algorithms, additional information is being incorporated to improve the predictions, but this example highlights the capability of these class of ML-models to forecast electric consumption based on easily available predictors. To train the three Neural Networks which results are displayed in Figure 20 we separated the dataset corresponding to the electric consumption data into a training set and a validation set. The Networks were trained and afterwards tested against the validation set. The figures show a randomly chosen 1000-register subset of these validation set results. As can be observe, there is a better match in the smaller range of electric consumption, possibly because the model does not contain enough information to capture all the variability in the upper range of electric consumptions.

However, these models suffer from an important limitation when they are to be used for long-term planning and decision-making, since it is not possible to anticipate the structure that the neural networks will adopt when faced with important changes in the configuration of electricity demand. For this reason, our complementary approach has consisted of developing EUReCA as a predictive module, if it has been previously adjusted to the actual electricity consumption. This is particularly complicated, given that EUReCA depends internally on a multitude of configurable parameters that we have been adjusting to achieve a correspondence between the electricity consumption observed and the internal parameters that configure the structure of the demand.

2.4.1 Building electric consumption according to sectorial typology in Spain

In this strategy, the first step was to find values for several important variables that determine the relationship between thermal demand and electricity consumption, such as the types of heating and cooling systems present and their prevalence. Unfortunately, we had to base this type of analysis on outdated and very general statistics because they were the only ones available. In this section, the results from the IDAE report "Analysis of Energy Consumption in the Spanish Households" from the SPAHOUSEC project [3] are considered.

The methodology employed in the SPAHOUSEC project encompasses the compilation of pertinent energy and socio-economic data within the residential sector, coupled with the conduction of telephonic and face-to-face surveys designed to gain insights into the living conditions of Spanish dwellings, as well as household equipment, energy consumption patterns, and behaviors.

In addition, in situ measurements of electrical consumption across 600 households contributed to the empirical data. Consequently, the insights derived from this report will provide us with a preliminary characterization of the electricity consumption of Spanish households, aiming to infer the electricity consumption attributable to HVAC systems. This distinction is crucial because the fundamental basis for the preliminary configuration of the thermal model generated by the EUReCA framework.

Overview of Building Types

Residential Buildings: Residential buildings in Spain encompass single-family homes and apartment buildings. These buildings primarily provide living spaces and related amenities. Energy consumption in residential buildings is primarily driven by heating, cooling, domestic hot water (DHW), and the use of household appliances. The report indicates that heating, DHW and cooling consumption in a household represents the largest energy consumer, especially in colder regions, and accounts for up to 70% of total energy consumption in the residential sector.

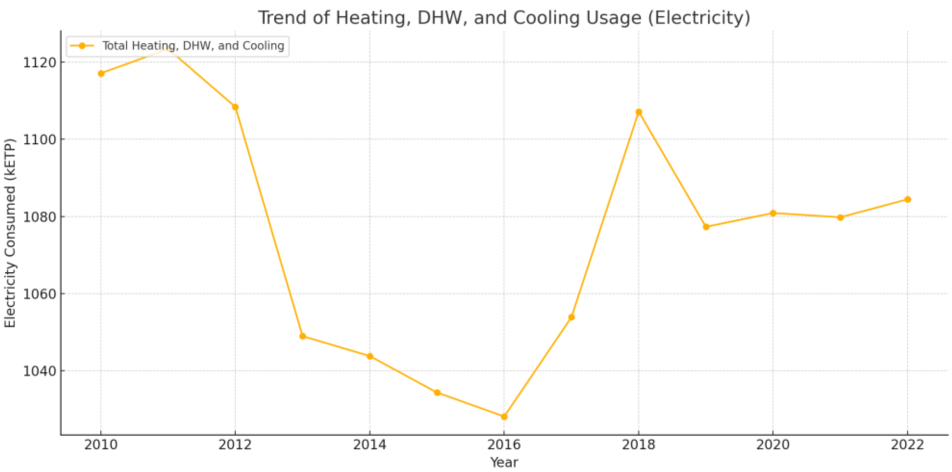

Figure 21 Evolution in recent years of electricity consumption in heating, DHW and cooling in a residential building.

Services and offices Buildings: Service buildings in Spain include commercial centers, offices, schools, and healthcare facilities. These buildings consume significant amounts of energy due to extensive HVAC systems, lighting, and equipment used for various services. The energy consumption in these buildings is a crucial aspect of the overall energy landscape, especially considering their operational hours and the need for comfort and functionality.

Industrial Buildings: Industrial buildings are used for manufacturing, storage, and other industrial activities. These buildings have high energy demands due to machinery, process heating, and other industrial processes. The energy consumption in industrial buildings is substantial, and it varies greatly depending on the specific industrial activities being carried out.

Tertiary Buildings: Tertiary buildings include commercial centers, shopping malls, and other large retail spaces. These buildings consume a significant amount of energy due to extensive HVAC systems, lighting, and equipment used for commercial purposes. The energy consumption in tertiary buildings is a crucial aspect of the overall energy landscape, especially considering the large footfall and operational hours of these establishments

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Estimation of Electrical Consumption by Sector

Based on the data from the SPAHOUSEC report, Table 2 shows the estimated consumption of electricity (in kiloton of oil equivalent, ktoe) across the different building sectors:

Table 2 Estimated consumption of electricity across the different building sectors.

Sector	Total Energy Consumption (ktoe)	Electricity Consumption (ktep)	Percentage of Total Consumption (%)
Residential	14,676	5,159	35.1
Service	7,851	3,492	44.5
Industrial	6,800	1,666	24.5
Tertiary	14,676	5,159	35.1

The total electrical consumption data is available from each CT by the DSO. For estimating the electricity consumption attributed to HVAC systems, different types of heating and cooling scenarios are assumed. In this context, the simultaneity coefficient, denoted as Ks, is defined. The simultaneity coefficient represents the proportion of possible electrical consumption that is likely to occur across all connected buildings to the same CT. It takes into account factors such as building occupancy schedules, vacant units, secondary residences, and other relevant parameters. For different types of buildings connected to the transformer substation, the simultaneity coefficient Ks is assigned. The following Table 3 provides a detailed breakdown of the types of heating and cooling systems used in different building sectors in Spain with its associated Ks.

Due to the lack of exact data on heating and cooling equipment in the households of Crevillente, the data in Table 3 is based on the SPAHOUSEC report, "Analysis of Energy Consumption in Spanish Households," which analyzes electrical consumption across 600 households during 2010 and 2011. Therefore, these are not specific data for Crevillente but serve as the starting scenario for thermal equipment of the building used in the predictive model. This model can then be adapted to reflect the reality in Crevillente.

Table 3 Occupancy, equipment, and lighting schedules for a commercial building.

	Residential $K_s = 0.55$	Services and Offices $K_s = 0.8$	Industrial $K_s = 0.75$	Tertiary $K_s = 0.85$
Heating System Type	**Percentage of Buildings (%)**			
No Heating System	17	0	8	0
Gas Boiler (Individual)	21	13	38	15
Gas Boiler (Centralized)	7	35	20	40
Oil boiler (Diesel)	6	15	1	0
Biomass	10	3	2	1
Electric Radiators	27	14	15	6
Heat Pumps (Splits, heating)	10	0	6	3
Centralized Heat Pumps (Heating)	2	20	11	35
Cooling System Type	**Percentage of Buildings (%)**			
No Cooling System	67	15	20	5
Heat Pumps (Splits, cooling)	25	10	30	15
Centralized Heat Pumps (Cooling)	8	75	50	80

Validation of Electrical Consumption Results Obtained in EUReCA

Based on the data of building typologies from the previous section, the EUReCA model has been executed to obtain electrical consumption estimations through energy simulations. The validation method consisted of

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the following steps:

- **Disaggregation of Consumption Data of Electric Station into building Demand:** This step involved breaking down the consumption data from the electric station to match the building demand patterns, described in the previous section.
- **Adjustment of the Simulation Data:** Adjustments were made to the simulation data to ensure accuracy and alignment with real-world conditions.
- **Validation of Expected Electrical Consumption According to HVAC Equipment Typology:** The expected electrical consumption was validated against the HVAC equipment typologies detailed in the previous section, focusing on CT32.

By way of illustration, the following Table 4 is an example of the application of the aforementioned methodology to a transformation centre (CT32):

Table 4 Description of the buildings of CT 32.

CT 32 Building Typologies	Number of Buildings	%	Climatable Area (m^2)
Residential	86	100%	22082
Service and Offices	0	0%	0
Industrial	0	0%	0
Tertiary	0	0%	0

The following Figure 22 presents the observed electrical consumption of the transformed center CT32 supplied by ENERCOOP and the predicted electrical consumption output from the EUReCA model.

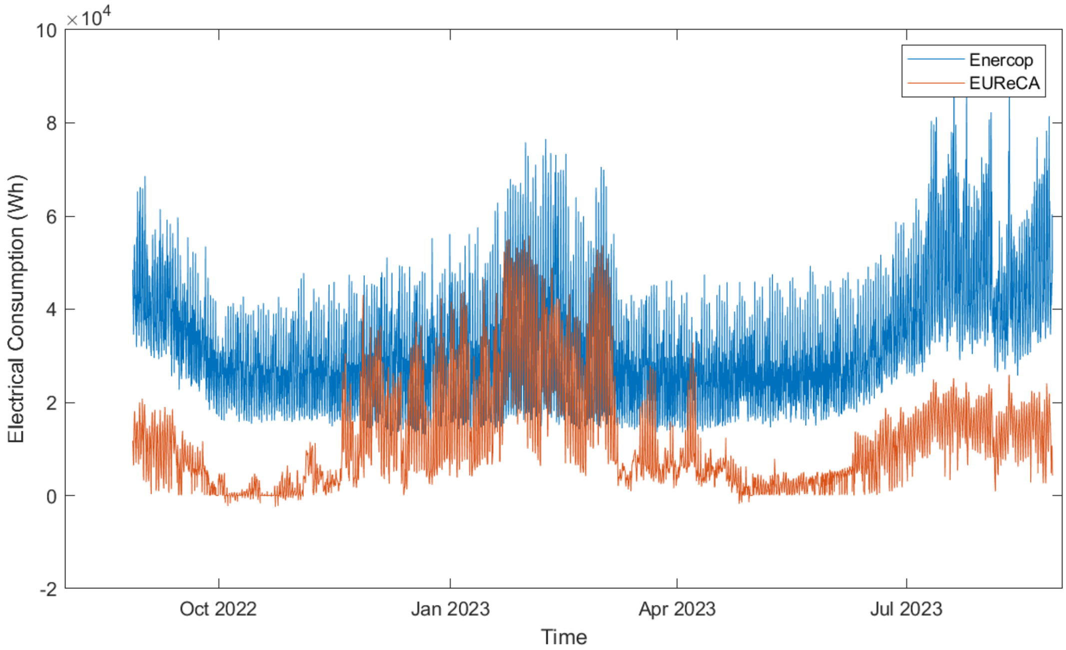

Figure 22 Comparison of the electricity consumption output of the EUReCA model (orange) and actual consumption provided by ENERCOOP (blue).

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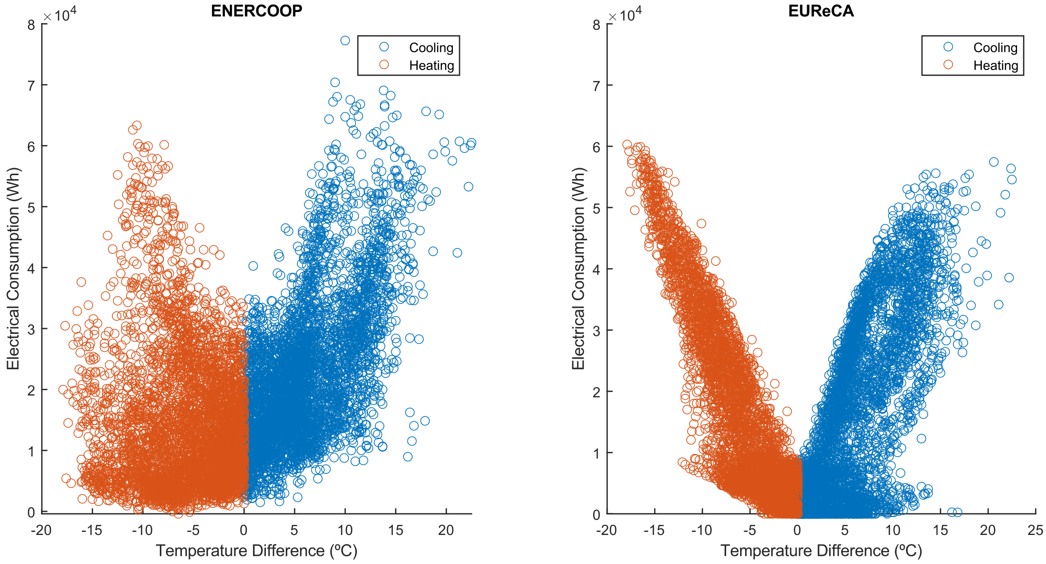

Figure 23 Comparison between the ENERCOOP and EUReCA consumption

The comparison between the observed and predicted consumption indicates that the EUReCA model provides a coherent estimation of electrical consumption, with the predicted values representing 40% to 60% of the actual total electricity consumption of the buildings. This validation supports the reliability and accuracy of the EUReCA model in estimating the electrical consumption for different building typologies.

Predictive model

The predictive model in the EUReCA framework is designed to refine electrical consumption estimates by incorporating various scenarios and patterns that affect energy use. After calibrating the model, the results are further refined using the following considerations:

- **Weekly Day Pattern:** The model incorporates variations in daily energy use. For instance, energy consumption tends to peak on weekdays during morning and evening hours when people are at home and using appliances.
- **House Occupation Pattern:** The model adjusts for times when houses are unoccupied, typically during work hours on weekdays, reducing the predicted energy consumption for these periods.
- **Energy Systems to Transform H&C Demand into Total Electricity Consumption:** The model differentiates between various heating and cooling systems, adjusting the energy consumption predictions based on the efficiency of each system.
- **Air Temperature:** The model uses temperature data to predict heating and cooling demands more accurately. For example, a drop in exterior temperature would result in higher heating energy consumption.
- **Typology (Percentage) of Building in the District/CT (Residential, Industrial, Tertiary):** The model adjusts predictions based on the proportion of residential, industrial, and tertiary buildings in the district. Each building type has different energy usage characteristics, which the model accounts for in its predictions.

The refined model outputs have been validated against actual consumption data provided by ENERCOOP (see previous section). This step has involved comparing the model's predictions with the real electrical consumption data to ensure accuracy. The validation process has helped to identify any discrepancies and allows for further adjustments to the model.

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This predictive model will be utilized in the upcoming deliverable D2.4 to estimate the electrical consumption attributable to heating, cooling, and domestic hot water (DHW) for the buildings in various scenarios. By leveraging the detailed scenarios and refined model, deliverable D2.4 aims to provide a complete and accurate assessment of the behavior of ECHOTSS in a real spatial environment such as the town of Crevillente.

3 The ECHO GRID module

In this section, the designed, implemented, and validated electric model for the evaluation of the impact of ECHO-TSS in the power grid will be presented. The aim of this model is to assess the effect on the grid that certain changes in the electricity demand in a specific distribution grid and related with given scenarios of energy system transformation and changes in the temperatures may have. Therefore, this model will allow analysing how such variables as real or reactive powers flowing through the grid or the voltage of the different buses is affected after a modification in the balance generation-consumption of one or several points in steady state. As a result, it will be possible to evaluate how the utilization of flexibility resources such as the ECHO-TSS devices may help to mitigate technical constraints in the grid.

3.1 Model structure, explanation, inputs and outputs

3.1.1 Methodology

A methodology has been designed for the implementation, validation and analysis of the impact that the ECHO system will have on the electricity grid. The different steps to be taken for its implementation are depicted in Figure 24.

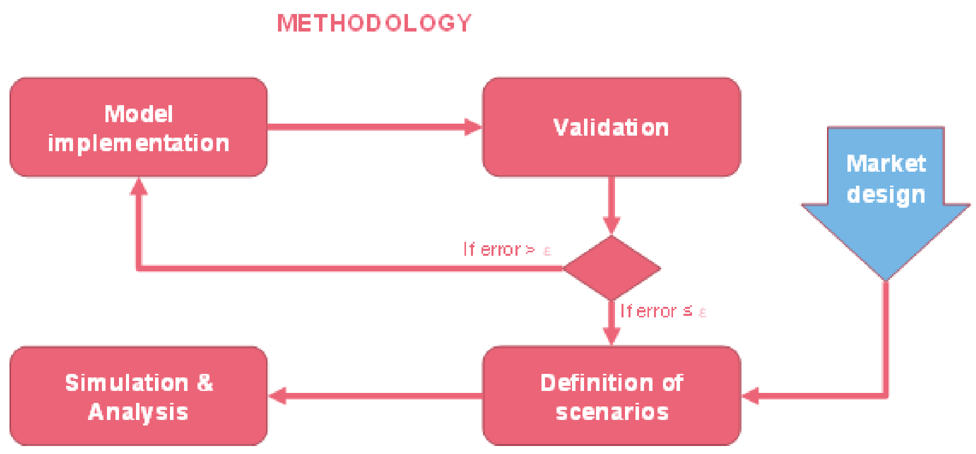

Figure 24 Methodology for the implementation, validation and impact analysis of ECHO in the grid.

The main characteristics of each of the phases for this methodology are the following:

<u>STEP 1: Model Implementation</u>

The model of the grid is based on the open-source software OpenDSS, a simulator designed by EPRI for electric power distribution systems to support distributed energy resources grid integration and grid modernization[3]. This phase is explained in detail in section 3.2 .

[3] https://www.epri.com/pages/sa/opendss

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STEP 2: Validation

Once the model had been implemented, it was necessary to validate it to guarantee the accuracy of the obtained results. This validation was performed by simulating the power flow of the considered grid in the steady state and comparing the values of the real and reactive power (P and Q obtained) in the reference bus with the real measurements at this point. For local distribution grids, as considered for the case studies in this project, the reference bus is the substation where the local grid and the main distribution or transmission network are interconnected. Moreover, the voltages obtained for each bus from the power flow simulation through the model can be compared to real measurements, when available, provided by the distribution system operator. In order to complete the validation of the model, the necessary adjustments will be made (regarding the element parameters considered during the design phase) so as to minimize as much as possible the obtained error ε, defined as the maximum value of the differences between each of the measured variables and the values calculated by the model. The model validation is explained in more detail in section 3.3 .

STEP 3: Definition of scenarios

This phase is based on the definition of scenarios used to test the impact of the ECHO storage system in the electric model of the grid for different levels of penetration. Such scenarios are defined considering the strategies to be used from the market point of view to exploit the flexibility related to the combination load-storage. Some scenarios can be defined according to the following situations:

- Evaluation of capacity to absorb energy surplus in periods of large photovoltaic production. In this scenario, the requirements of storage capacity provided by ECHO, combined with traditional load flexibility, will be evaluated.
- Load shifting strategies to solve technical constraints that may appear in the distribution grid. In this scenario, the ability of consumers with the ECHO system installed to provide the distributor with mechanisms to solve technical constraints in the grid (e.g. a power line overload) will be analysed.
- Market strategies to maximize the economic profits that may be obtained by consumers providing flexibility (Demand Response Providers) and the stakeholders (e.g. energy trading companies) which may request such services (Demand Response Requesters).

Additional scenarios related to the full exploitation of flexibility related to the ECHO storage system will be considered according to the progress of the project.

STEP 4: Simulation & analysis

This phase is the final step of the process and is completed after calibrating the model and incorporating all the requested information into the prototype. Using simulations, it is possible to assess the impact of an ECHO system on the grid by considering the storage capacity of grid users for different flexibility services. Similarly, the maximum capacity admissible by the grid when installing the ECHO system could be evaluated by a reliability analysis, considering technical, economic, and environmental criteria.

3.1.2 Data model inputs

Information required to feed the electric model can be classified according to three blocks, according to the data provider:

- **Block 1: Distributor data**. This information is related to the physical architecture of the grid, and it is owned by the distribution grid operator. Information from this block is very detailed and specific, so that it is not commonly available. Moreover, some of this information may be confidential.
- **Block 2: Public data.** They are related to the ambient temperature profiles, which affect the impedance of power lines, as it will be described in section 3.2 Additionally, values for some parameters of the power lines (such as typical impedance, reactance or capacitance) come from public type projects may be necessary in case of lack of information from Block 1, as well as in order to validate or adjust the data provided by the distributor.

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- **Block 3: Scenarios generator data.** This information is provided by other tools and models, and it is obtained after application of hypotheses based on which the different simulation scenarios are defined.

Specifically, this information must be provided to the model in the following way:

a) **Block 1. Distributor Data**

- Input #1.1: Power lines. It is a .cvs file composed of twelve columns and as many rows as power lines exist in the modelled grid. Information provided in each column is the following:
    i. Identification of the power line. This is a numeric code provided by the distribution company
    ii. The standard classification of conductors the power line is made of. This is an alphanumeric code provided by the distribution company.
    iii. Type of line according to its installation (aerial, underground). This is an alphanumeric code provided by the distribution company.
    iv. Initial bus. This is a numeric code provided by the distributor.
    v. Final bus. This is a numeric code provided by the distributor.
    vi. Nominal voltage, expressed in Volts (V).
    vii. Nominal current, expressed in Amperes (A).
    viii. Length of the line, expressed in kilometres (km).
    ix. Resistance of the line at 20°C, expressed in ohms (Ω).
    x. Reactance of the line, expressed in ohms (Ω)
    xi. Capacitive susceptance of the line, expressed in Siemens (S).
    xii. Type of service. This is a binary code, which is equal to one if the power line is in service, being zero otherwise.

- Input #1.2: Transformation centres. It is a .cvs file composed of nine columns and as many rows as transformation centres (CT) exist in the modelled grid, plus the titles row. Information provided in each column is the following:
    i. Identification of the transformation centre. This is a numeric code provided by the distributor.
    ii. Name of the transformation centre. This is an alphanumeric code provided by the distributor.
    iii. High voltage bus. This is a numeric code provided by the distributor.
    iv. Low voltage bus. This is a numeric code provided by the distributor.
    v. Nominal voltage at the high voltage bus, expressed in Volts (V).
    vi. Nominal voltage at the low voltage bus, expressed in Volts (V).
    vii. Nominal power, expressed in kilovolt-amperes (kVA)
    viii. UTM geographic coordinate “x”.
    ix. UTM geographic coordinate “y”.

- Input #1.3: Buses. It is a .cvs file composed of five columns and as many rows as buses exist in the modelled grid, plus the titles row. Information provided in each column is the following:
    i. Identification of the bus. This is a numeric code provided by the distribution company.
    ii. Type of bus. There are three possibilities: slack (just one bus in the whole system), voltage control or load.
    iii. Nominal voltage, expressed in Volts (V)
    iv. UTM geographic coordinate “x”.

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v. UTM geographic coordinate “y”.

It is important to guarantee that buses included in columns *ii* and *iii* of Input #1.1 and buses included in columns *iii* and *iv* of Input #1.2 appear in the Input #1.3, as well as checking that there are no isolated buses (not connected to any power line or transformation centre).

- Input #1.4. Load and production curves. This is a group of .cvs files composed of ten columns and as many rows as hours are considered for the simulation period, plus the titles row (i.e. for annual basis, the file will have 8760 rows for data plus the titles row). The number of files will be equal to the number of buses through which power is injected to or extracted from the modelled system. Information provided in each column is the following:
    i. Year corresponding to the provided value of power (four numeric characters, from 0000 to 9999).
    ii. Month corresponding to the provide value of power (two numeric characters, from 01 to 12).
    iii. Day corresponding to the provided value of power (two numeric characters, from 01 to 31).
    iv. Hour corresponding to the provided value of power (two numeric characters, from 01 to 24).
    v. Real power demanded at the considered bus (supplied to the consumers connected to such bus), expressed in watts (W).
    vi. Real power injected to the considered bus (supplied by the generation devices connected to such bus), expressed in watts (W).
    vii. Reactive power in the first quadrant corresponding to the considered bus, expressed in reactive volt-amperes (var).
    viii. Reactive power in the second quadrant corresponding to the considered bus, expressed in reactive volt-amperes (var).
    ix. Reactive power in the third quadrant corresponding to the considered bus, expressed in reactive volt-amperes (var).
    x. Reactive power in the fourth quadrant corresponding to the considered bus, expressed in reactive volt-amperes (var).

b) Block 2. Public Data

- Input #2.1. Temperature profile. This is a .cvs file composed of five columns and as many rows as hours are considered for the simulation period, plus the titles row (i.e. for annual basis, the file will have 8760 rows for data plus the titles row). Information provided in each column is the following:
    i. Year corresponding to the provided value of power (four numeric characters, from 0000 to 9999).
    ii. Month corresponding to the provide value of power (two numeric characters, from 01 to 12).
    iii. Day corresponding to the provided value of power (two numeric characters, from 01 to 31).
    iv. Hour corresponding to the provided value of power (two numeric characters, from 01 to 24).
    v. Ambient temperature at the location of the modelled grid, expressed in Celsius degrees (°C). The source for this data is the same as for section 2.2 .

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- Input #2.2. Typical values for power lines parameters. This is a .cvs file composed of five columns and as many rows as types of power line exist in the modelled grid. Information provided in each column is the following:
    i. The standard classification of conductors the power line is made of. This is an alphanumeric code provided by the distribution company.
    ii. Nominal voltage, expressed in Volts (V).
    iii. Typical value of resistance at 20ºC, expressed in ohms per kilometre (Ω/km).
    iv. Typical value of reactance, expressed in ohms per kilometre (Ω/km)
    v. Typical value of capacitive admittance, expressed in Siemens per kilometre (S/km).

c) Block 3. Scenarios generator data.

In this block, files built according to the structure provided to inputs #1.4 or #2.1 could be introduced to the model in order to simulate the scenarios that could be considered.

3.1.3 Expected outputs

Outputs provided by the model will be those related to the solution of the power flow:

- Complex voltage (module and phase) at each bus of the system, expressed in kilovolts (kV) and degrees (º).
- Real and reactive power flows at the reference bus.
- Reactive power flow at the voltage-controlled buses, in reactive volt-amperes (var).
- Real and reactive power flows at the beginning and at the end of each power line.
- Load level of the different power lines and transformation centres.

This information could be provided in a single .cvs file. Additionally, it could be also graphically represented in a floor map when UTM geographic coordinates are supplied, as shown in Figure 25.

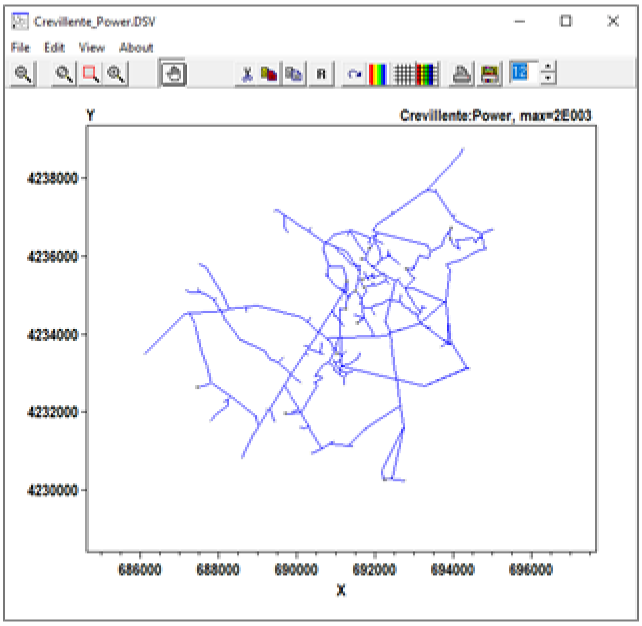

Figure 25 Example of electric chart on the floor map provided by the model.

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3.2 Implementation of the electric model

The electric model is based on OpenDSS software developed by the Electric Power Research Institute (EPRI). The proposed program is a general-purpose frequency-domain simulation engine for modeling electric distribution systems. It allows the performance of different studies related to distribution planning and power quality in both transient and steady-state regimes.

According to the scope of the ECHO project, OpenDSS will be used to model a specific distribution grid to perform power flows in the steady state to determine the impact of different strategies related to the management of ECHO-TSS devices in the power grid. In addition, this model allows us to assess the impact of the introduction of ECHO-TSS at a specific level on the power grid..

3.2.1 Modelling of elements in the power system

The modelling of the elements of the grid is based on a modal admittance approach (Alcázar-Ortega, et al., 2019). Therefore, power lines and transformers are modelled according to the concentrated parameters "pi" approach, where each element is considered as an electric circuit with a series branch, with a resistance *(R_s)* and a reactance *(X_s)* connected in series, and two shunt-branches at the beginning and the end of this circuit, including the capacitive susceptance *(B_p)* of the line.

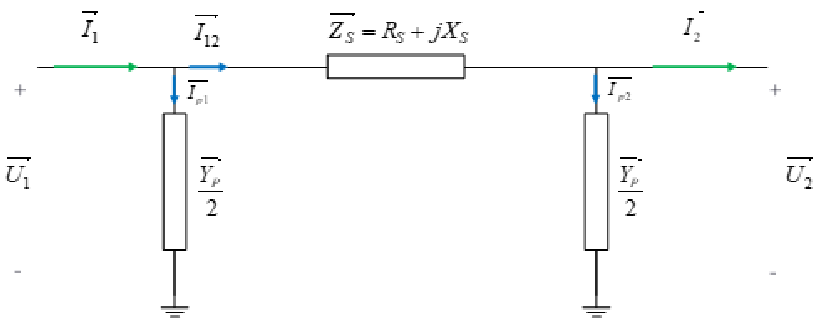

Figure 26 "π" model for a power line.

In this model, depicted in Figure 26, R_s and X_s are used to build the series complex impedance of the line or transformer:

$$\overline{Z_s} = R_s + jX_s \tag{3.1}$$

On the other side, B_p is used to calculate the shunt admittance of the line or transformer, which is divided into two as the model considers that a half of the capacitive effect is concentrated at the beginning of the line, while the other half takes place at the end of the line. Notice that the shunt conductance has been neglected.

$$\frac{\overline{Y_p}}{2} = j\frac{B_p}{2} \tag{3.2}$$

The values to feed this model are obtained from the file "Input 1.1". However, the resistance R_s may be affected by the temperature at which the grid is. Indeed, the value of resistance provided by the distribution company is at a standard temperature of 20 °C. In case the external temperature is different, the model considers the actual temperature for the simulated hour, according to the following expression:

$$R_s' = [1 + \beta \cdot (T_2 - 20°\text{C})] \cdot R_s \tag{3.3}$$

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where:

- R'_s is the resistance of the element at the actual temperature of the grid.
- R_s is the standard resistance of the element at the temperature of 20 °C.
- β is the coefficient of variation with temperature. It takes the value of $3.93 \cdot 10^{-3}$ °C^{-1} for copper[4] and $4.07 \cdot 10^{-3}$ °C^{-1} in case of aluminium[5].
- T_2 is the actual temperature at which the grid is. Values for T_2 are obtained from the file "Input #2.1".

Once the parameters for each element (power line or transformer) have been updated, the mathematical model of the whole grid is obtained throughout by the nodal admittance matrix. This is a square and symmetric matrix of dimensions *NxN*, being *N* the number of buses of the system. The number of buses *N* will be equal to the number of rows of the file "Input #1.3" minus one.

The architecture of the admittance matrix is represented next:

$$[\bar{I}] = [\bar{Y}] \cdot [\bar{V}] \rightarrow \bar{Y} = \begin{bmatrix} \overline{y_{11}} & \overline{y_{12}} & \cdots & \overline{y_{1N}} \\ \overline{y_{21}} & \overline{y_{22}} & \cdots & \overline{y_{1N}} \\ \vdots & \vdots & \ddots & \vdots \\ \overline{y_{N1}} & \overline{y_{N2}} & \cdots & \overline{y_{NN}} \end{bmatrix} \tag{3.4}$$

where:

- *[I]* is a vector where each component is the net balance of currents at each of the *N* buses of the grid.
- *[V]* is a vector where each component is the complex voltage at each of the *N* buses of the grid.
- y_{ki} are the elements of the admittance matrix. Each of these elements is a two components vector (a complex number) which is calculated from the series and shunt admittances of the different elements (lines or transformers) of the grid. They are calculated diversely depending on if they are in the diagonal or out of the diagonal of the matrix:
    - Elements in the diagonal (y_{kk}) are calculated as the sum of admittances connected to the bus *k*
    - Elements out of the diagonal (y_{ki}) are calculated as the sum of admittances that connect the bus *i* with the bus *k*, multiplied by -1. Notice that as the admittance matrix is symmetric, $y_{ki}=y_{ik}$

According to Figure 26, the shunt branch is already calculated as an admittance. However, the series branch represents an impedance, and it must be turned into an admittance, as shown next:

$$\bar{Y_s} = \frac{1}{\bar{Z_s}} = \frac{1}{R_s + jX_s} = G_s + jB_s \tag{3.5}$$

Each element of the admittance matrix will have a real part G_{ik} and an imaginary part B_{ik}. Therefore, this matrix can be represented as follows:

[4] UNE 20003:1954 (IEC 60028:1925) - Annealed and industrial type copper, for electrical applications

[5] UNE-EN IEC 62641:2023 - Conductors for aerial power lines. Aluminum and aluminum alloy wires for conductors wired in concentric layers

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$$\bar{Y} = \begin{bmatrix} \overline{y_{11}} & \overline{y_{12}} & \cdots & \overline{y_{1N}} \\ \overline{y_{21}} & \overline{y_{22}} & \ddots & \overline{y_{1N}} \\ \vdots & \vdots & & \vdots \\ \overline{y_{N1}} & \overline{y_{N2}} & \cdots & \overline{y_{NN}} \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} G_{11}+jB_{11} & G_{12}+jB_{12} & \cdots & G_{1N}+jB_{1N} \\ G_{21}+jB_{21} & G_{22}+jB_{22} & \ddots & G_{2N}+jB_{2N} \\ \vdots & \vdots & & \vdots \\ G_{N1}+jB_{N1} & G_{N2}+jB_{N2} & \cdots & G_{NN}+jB_{NN} \end{bmatrix} \end{bmatrix} \quad (3.6)$$

The admittance matrix represents the mathematical model of the system, and it remains constant for all the simulations of a specific scenario.

3.2.2 Calculus method for power flow evaluation

The power flow algorithm determines the value of complex voltage (module and phase) and complex power balance (real and reactive) in each bus of the considered electric system. Once these four variables are obtained, the working points of the system can be determined.

Depending on the bus type, two of these variables are known; thus, the remaining two variables per bus must be determined by a power flow calculation. Therefore, busses can be classified into three types:

Type 1: slack bus. This bus is unique in the whole system and all the voltage phases are referred to it, taking usually the value of zero for the voltage angle at this point. The voltage module is also known as this bus must have reactive power control to maintain this magnitude in the desired value. Therefore, variables to be calculated in this bus are real and reactive power.

- Type 2: Voltage control bus. In this kind of buses, there are mechanisms (banks of capacitors and coils, synchronous compensators, statcoms, …) able to control the voltage magnitude to guarantee that it remains at a specific value. The real power balance in these buses is also known, so that variables to be calculated are the voltage phase and the reactive power balance.
- Type 2: Load bus. In these buses, there are no mechanisms to control the voltage. Real and reactive power values are known (usually related to connected loads or generators supplying a specific power). Therefore, variables to be calculated are voltage phase and magnitude.

Real and reactive power at the buses where these magnitudes are unknown can be determined by the following equations:

$$P_k = V_k \cdot \sum_{i=1}^{N} V_i \cdot [G_{ki} \cdot \cos(\delta_k - \delta_i) + B_{ki} \cdot \sin(\delta_k - \delta_i)] \quad (3.7)$$

$$Q_k = V_k \cdot \sum_{i=1}^{N} V_i \cdot [G_{ki} \cdot \sin(\delta_k - \delta_i) - B_{ki} \cdot \cos(\delta_k - \delta_i)] \quad (3.8)$$

where:

- P_k and Q_k are the net values of real and reactive power in the bus k. Net values mean that they represent the balance between the power injected to the system by this bus and the power extracted from the system by this bus (generation minus loads).
- V_k is the voltage magnitude at the bus k (where P_k and Q_k are being evaluated).
- δ_k is the voltage phase at the bus k.
- V_i is the voltage magnitude at each of the i buses of the system, including the bus k.
- δ_i is the voltage phase at each bus i.
- G_{ki} and B_{ki} are, respectively, the real and the complex parts of the admittance matrix element located at the row k and the column i. These values are obtained from eq. 3.6.

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As can be seen, the solution of the system of equations is not evident, as the power balance in one bus depends on the voltage of all the other busses of the system (and the same occurs with the voltages). Therefore, an iterative process must be applied to determine the solution for different unknowns. In power systems analysis, there are two basic methods to address this problem: Newton-Raphson and Gauss-Seidel (so-called “Normal” current injection mode in OpenDSS). Gauss-Seidel is faster and relatively simple. Newton-Raphson is more robust for systems that are difficult to solve, but it has the complexity of working with large dimension matrixes, which have to be inverted. Therefore, Gauss-Seidel is the default method in OpenDSS.

The expression used to calculate the complex voltage according to Gauss-Seidel is the following:

$$\bar{V}_k^{(n+1)} = \frac{1}{\overline{y_{kk}}} \cdot \left[\frac{P_k - jQ_k^{(n)}}{\left(\bar{V}_k^{(n)}\right)^*} - \sum_{\substack{i=1 \\ i \neq k}}^{N} \overline{y_{ki}} \cdot \bar{V}_i^{(n)} \right] \tag{3.9}$$

where:

- $V_k^{(n+1)}$ is the voltage magnitude at the bus *k* for the iteration that is being calculated (n+1).
- $V_k^{(n)}$ is the voltage magnitude at the bus *k* obtained in the previous iteration (n).
- $V_i^{(n)}$ is the voltage magnitude at each of the *i* buses of the system obtained in the previous iteration (n).
- P_k and Q_k are the net values of real and reactive power in the bus k. In the case of voltage control buses, $Q_k^{(n)}$ is the value obtained by means of eq. 3.8 in the previous iteration (n).
- *N* is the number of buses in the considered system.
- y_{kk} is the element of the admittance matrix (from eq. 3.6) located at the row k and column k.
- y_{ki} is the element of the admittance matrix (from eq. 3.6) located at the row k and column i.

Notice that eq. 3.9 is a vector expression, which provides a complex number composed of two components. Therefore, the variables to be introduced are also complex numbers. Conversely, equations to calculate values for real and reactive power (eq. 3.7 and eq. 3.8) are scalar expressions where the variables to be introduced are real numbers.

The method to apply the iterative process in order to calculate the final value of all the unknowns is shown in Figure 27:

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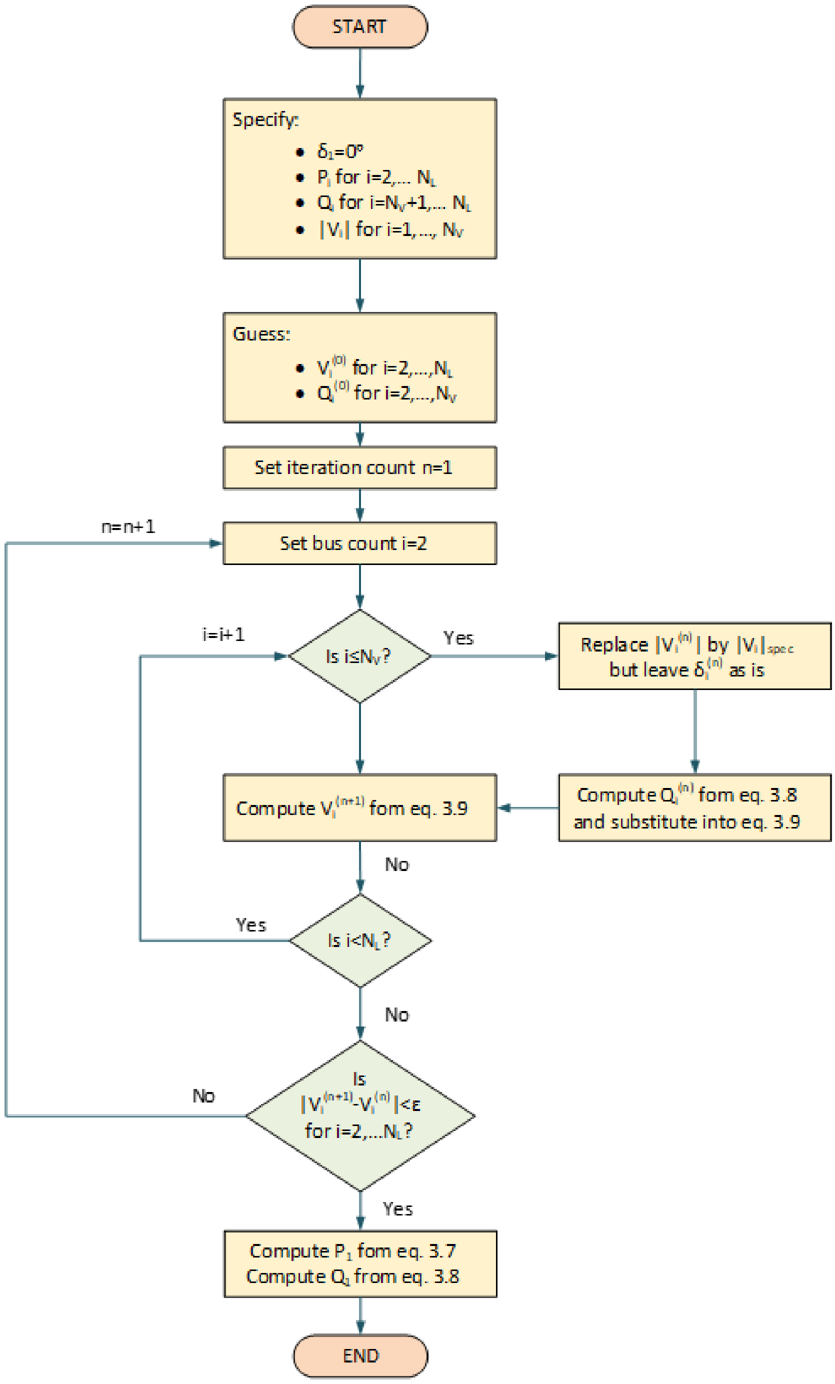

Figure 27 Flow chart for power flow computations using the Gauss-Seidel algorithm

Source: adapted from (Glover, et al., 2007)

The diagram shown in Figure 27 is based on the following coding of buses:

- Slack bus: i=1
- Voltage control buses: i=2,…,N_V
- Load buses: i=N_V+1,…,N_L

ε represents the maximum admissible error, which uses to be in the order of 10^{-3}.

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Once the complex voltage has been determined for all the buses, all line powers is calculated according to the following expressions:

$$P_{ik,i} = V_i^2 \cdot G_{s_{ik}} - V_i \cdot V_k \cdot G_{s_{ik}} \cdot \cos(\delta_i - \delta_k) - V_i \cdot V_k \cdot G_{s_{ik}} \cdot \sin(\delta_i - \delta_k) \quad (3.10)$$

$$Q_{ik,i} = -V_i^2 \cdot \left[B_{s_{ik}} + \frac{B_{p_{ik}}}{2}\right] - V_i \cdot V_k \cdot G_{s_{ik}} \cdot \sin(\delta_i - \delta_k) + V_i \cdot V_k \cdot B_{s_{ik}} \cdot \cos(\delta_i - \delta_k) \quad (3.11)$$

Where:

- $P_{ik,i}$ and $Q_{ik,i}$ are the values of real and reactive power, respectively, flowing from the bus *i* to the bus *k*, measured at the bus *i*
- V_i and V_k are the voltages (magnitudes) of buses *i* and *k* (beginning and end of the line)
- δ_i and δ_k are the voltage phases of buses *i* and *k* (beginning and end of the line)
- G_{sik} is the real part of the series admittance of the line starting at bus *i* and ending at bus *k*
- B_{sik} is the imaginary part of the series admittance of the line starting at bus *i* and ending at bus *k*
- B_{pik} is the imaginary part of the shunt admittance of the line starting at bus *i* and ending at bus *k*

Notice that expressions 3.10 and 3.11 are calculated with the series and shunt admittances of the line, while equations 3.7 and 3.8 are obtained from the elements of the admittance matrix.

3.2.3 Implementation in software OpenDSS

There are two primary methods to interact with OpenDSS:

1. Graphical User Interface (GUI). It provides a structured environment for the design, implementation and simulation of power system cases.
2. Component Object Model (COM) interface.

The GUI method was used to introduce the element parameters into the model and perform one-step simulations. However, this method is not appropriate for working with temporary series because it does not allow simulations in loop. Therefore, the COM interface was used to implement the simulations because it allows the programming of specific grid characteristics using Python.

Method 1. Graphical User Interface

The screen of the OpenDSS interface that appears when the program is started is shown in Figure 28. The different parts of this interface, marked with red numbers in brackets, are the following:

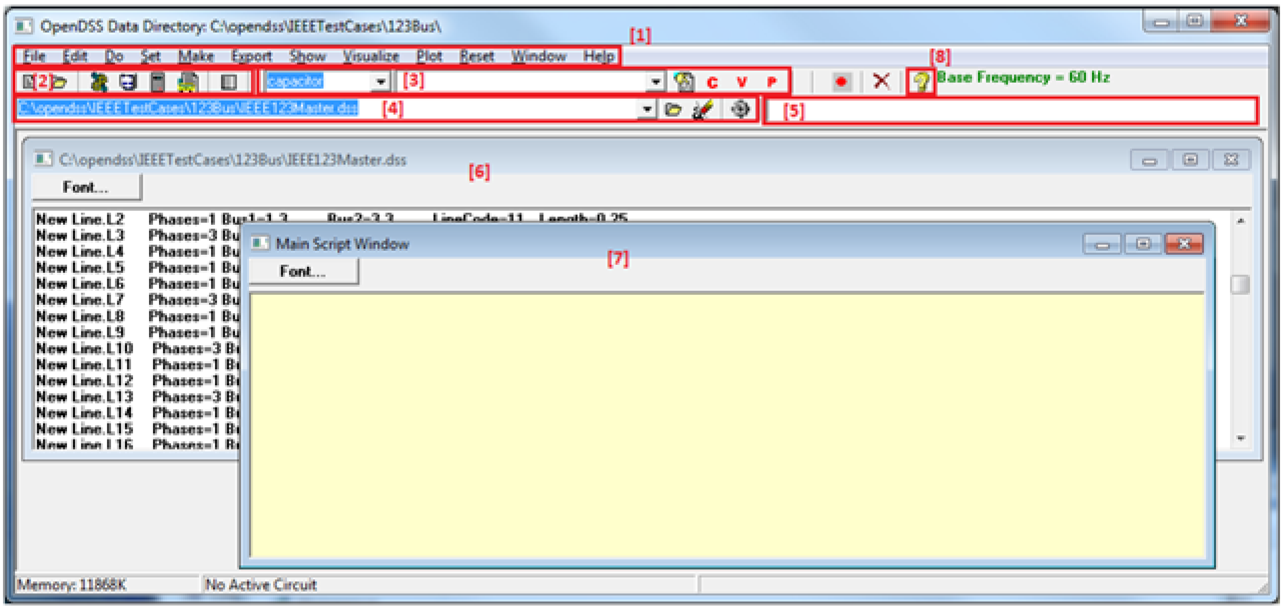

Figure 28 Opening screen of OpenDSS.
Source: opendss.epri.com

[1] Menu structure, which includes:

- The Set menu, to introduce the network parameters.
- The Export menu, to save the obtained reports to .cvs files.
- The Show menu, to display the information provided in reports in graphical user interface.
- The Visualize menu, to obtain a graphical output of the selected element of the grid.
- The Plot menu, to obtain the graphical output of the whole system.

[2] Toolbar. It provides direct access to the most frequent commands of OpenDSS.

[3] Elements tool. It allows the user to choose a circuit element for edition or visualization purposes.

[4] Script tools. They are used to choose the script to be run among the opened ones.

[5] Results bar. It provides a summary of results, which can be also accessed by means of the menu Show > Result Form.

[6] Script window. It is used to edit .dss files.

[7] Main screen window. This is like a "notepad" for OpenDSS where small commands can be written, after what they can be run throughout the "Do" command. The content of this window is kept between sessions.

[8] Help button. It provides a tree-view guide about the different script commands.

The methodology to be followed is depicted in Figure 29.

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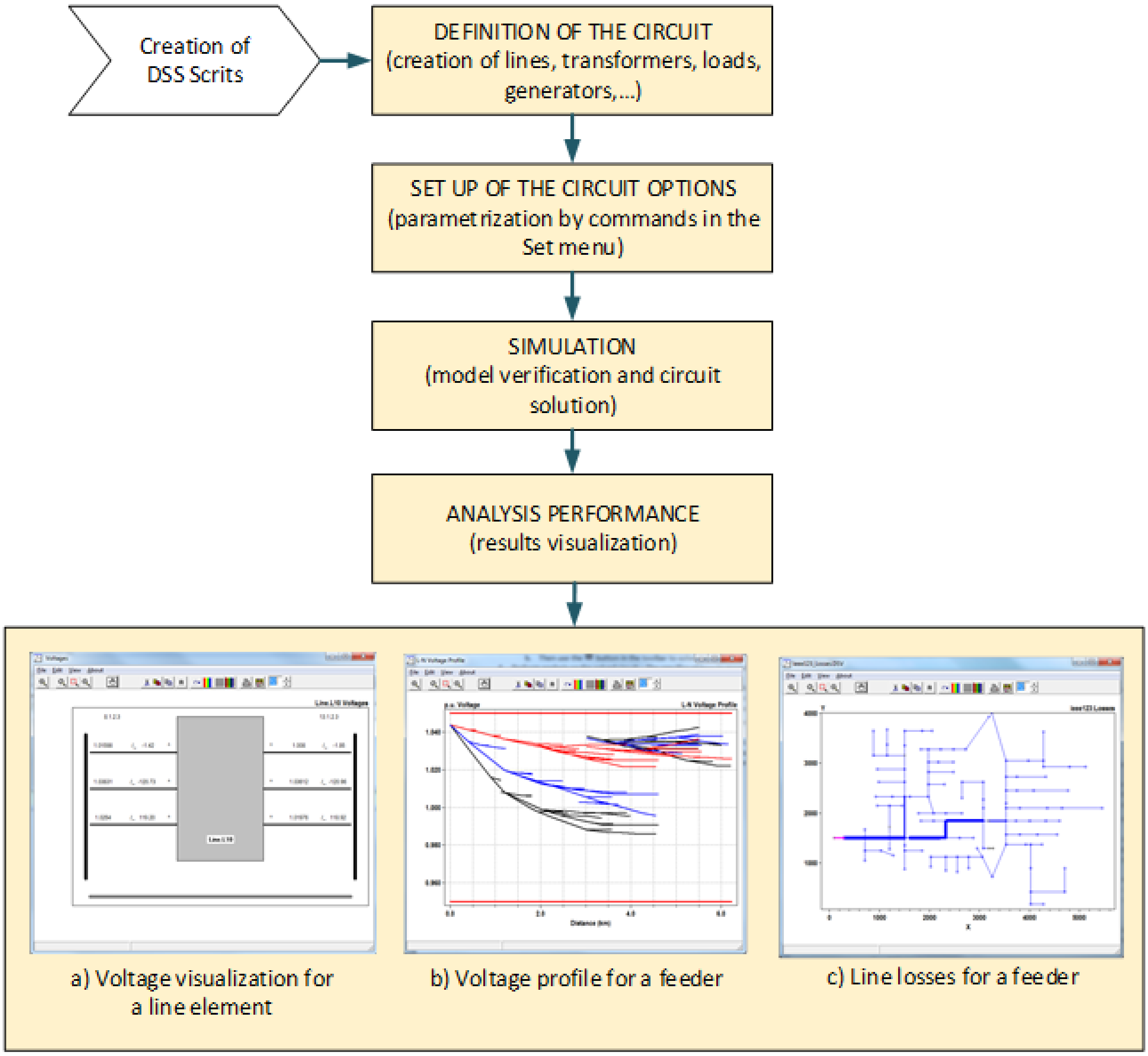

Figure 29 Workflow to interact with OpenDSS via Graphical User Interface. Source: based on: opendss.epri.com

<u>Method 2. COM Interface</u>

By using this interface, it is possible to design custom solutions and features from an external program, with the possibility to execute the functions of the simulator, including the definition of the model data. This interface is implemented with an in-process server dynamic-link library (DLL), providing the possibility to compute other languages or platforms, such as Python, VBA, Matlab, JavaScript or C. Choosing a specific language would depend on the pursued objective:

- Python is highly recommended for an easy and a fast development.
- Matlab is a good option for advanced analysis.
- C is appropriate for desktop applications and robust services.
- VBA could be useful for automation in Microsoft Office environments.
- JavaScript may be considered for web development and server-side applications, although is less common for such a specific use.

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In our case, Python was chosen to work with the COM interface for the ECHO GRID model implementation, as this is a flexible high-level language that allows incorporating libraries (Panda Power[6]) to simulate in an easier and faster way.

In summary, Figure 30 depicts the structure of the ECHO GRID model based on OpenDSS.

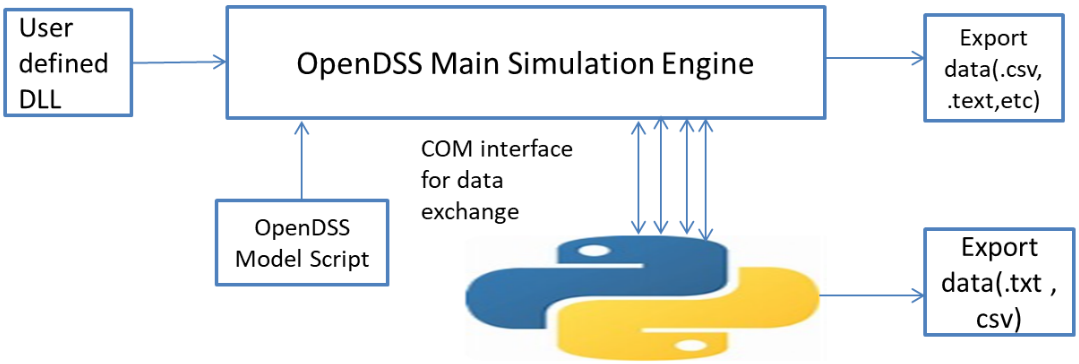

Figure 30. Workflow to interact with OpenDSS via COM Interface.
Source: based on opendss.epri.com

3.3 Model validation

After simulating the model for the first time with the base-case data, it is necessary to verify the obtained results to validate their accuracy and reliability. This process can be divided into the following steps:

a. Preliminary validation of the obtained values for loads and voltages in busses. In the base case, the voltage values should be close to the nominal value for each of them (approximately, one per unit). The voltage phase should be small (in any case, lower than the stability limit of 30º). Finally, the power balance in the whole system should be balanced (the neat power injected to the system should be lightly higher but approximately equal to the power extracted from the system as power losses are low).
b. Comparison of the obtained values with real data obtained from measurements. It would be useful to compare the voltages of all busses and the power throughout the power lines when available. This information is sometimes missing; therefore, a comparison should be made between the power interchange values at the slack bus.

If deviations between measurements and simulations are large (more than 15%), it is necessary to review the parameters introduced into the model for power lines and transformers. In this case, the check is performed using the standard values provided in file input #2.2. If the values of some parameters are very different from those considered in this file, they are replaced by standard values, and new simulations are performed to validate this action.

.

3.3.1 Preliminary results

The model validation has been done with data provided by the partner ENERCOOP about the distribution grid they own in Crevillente (Spain), which will be further detailed in section 3.4. Simulations with OpenDSS

[6] https://pandapower.readthedocs.io/en/latest/

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can be done on a daily, weekly, monthly or annual basis. For validation purposes, a daily simulation has been done, obtaining the results showed below:

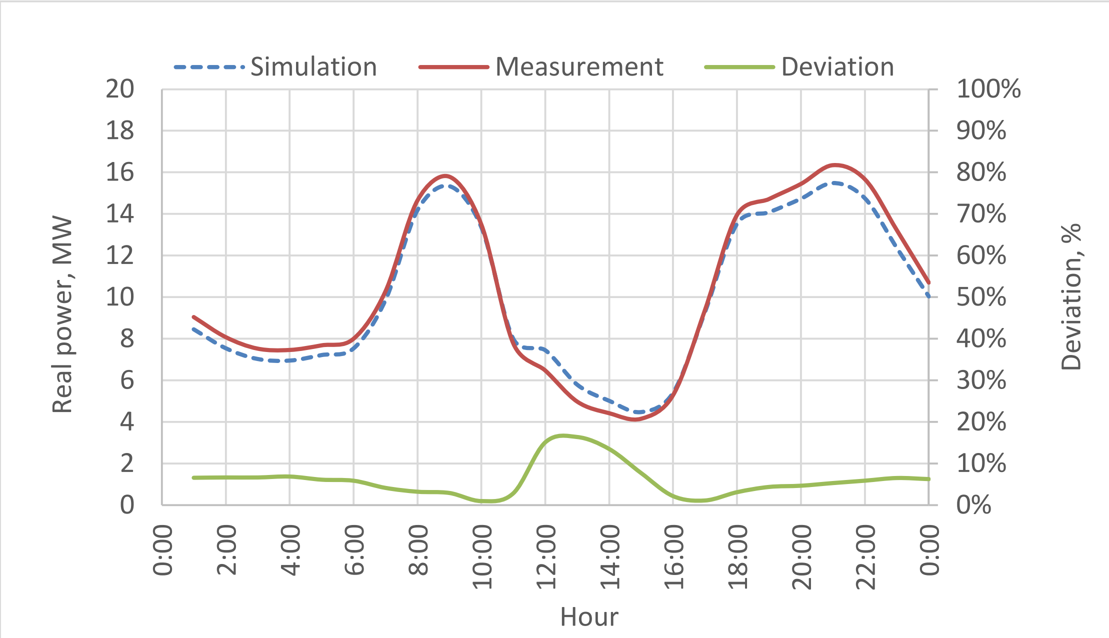

Figure 31. Real and simulated load curve at the slack bus on 19/01/2023

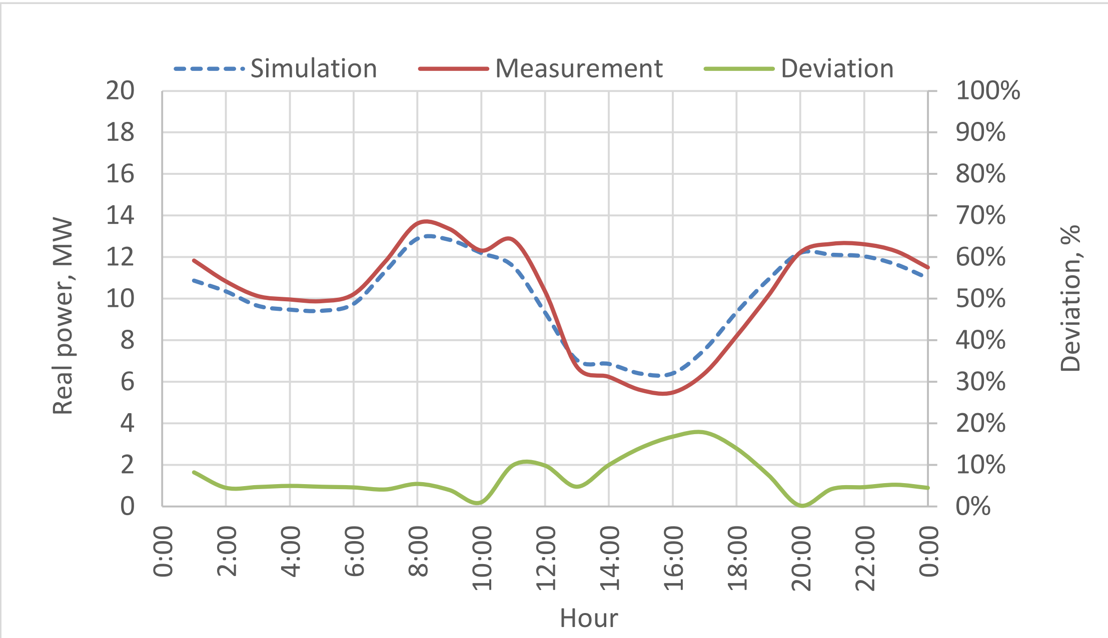

Figure 32. Real and simulated load curve at the slack bus on 14/07/2023

The considered curves correspond to the extreme demand days in winter and summer. Thus, 19/01/2023 was the day of the year with a maximum consumption for heating, while 14/07/2023 was the day with the maximum consumption for air conditioning. According to the obtained results, the deviation between both curves remains most of times below 10%. Just during some hours, deviation reaches 18%, probably because some small photovoltaic units that have not been considered due to the lack of information. However, simulated and measured curves are very similar and the accuracy of simulated values is acceptable. On the other side, all voltages in buses have been reviewed, being all of them close to the nominal voltage and all phase angles below 30°.

3.4 Case study: Crevillente distribution power grid

The case study where the ECHO GRID model has been applied corresponds to the distribution grid of the town of Crevillente, located in Spain, which is owned by the company "*Cooperativa Eléctrica San Francisco de Asis*" which is part of ENERCOOP Group. This company operates and maintain the distribution grid and the transformation centres of the municipality of Crevillente, as well as the 80 MVA substation, which connects the ENERCOOP infrastructures to the main network, owned by *"i-de Redes Inteligentes"* (Iberdrola Group) at a voltage of 132 kV.

3.4.1 Grid description

The distribution grid of Crevillente comes from the mentioned substation, which transforms the voltage level from 132 kV to 20 kV. This is done by means of two 40 MVA transformers. This substation is considered as the slack bus to evaluate the power flow by the ECHO GRID model.

Figure 33 Substation of Crevillente.
Source: ENERCOOP, https://www.grupoenercoop.es/instalaciones-tecnicas/

Downstream, there are four delivery centres (Monja, Arquet, I-8 and Tren), which feed the 155 transformation centres of the Crevillente's distribution grid. Each of these transformation centres reduces the voltage from 20 kV to 400 V to supply the electricity to the final consumers. Transformation centres are in the urban area of the town, but also in industrial parks and rural areas.

The grid is composed of 24881 buses, which are interconnected among them and to the transformation centres by 25192 power lines. Indeed, there are more than 400 km of power lines, aerial and undergrown, corresponding 115 km to medium voltage power lines (at a level of 20 kV) and 293 km to low voltage (at 400/230 V).

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Figure 34 Maintenance works on a distribution power line.
Source: ENERCOOP, https://www.grupoenercoop.es/instalaciones-tecnicas/

Based on this architecture, the ECHO GRID model has been particularized for this case, all the elements being characterized and parameterized according to the information provided by ENERCOOP. In addition, load and generation curves for each transformation centre on an hourly basis have been also introduced to the model.

3.4.2 Hypothesis and assumptions

The ECHO GRID model requires detailed information about the architecture and characteristics of the different grid elements, as well as about the balance between load and generation at the transformation centres. However, this information is sometimes difficult to obtain (even for the distribution company), so that some assumptions have been made to overcome these barriers, as summarized below:

- Regarding transformation centers, only the transformation rate and nominal power were available. Therefore, the remaining characteristics (iron loss, short-circuit voltage, real part of such voltage and open-circuit current) were taken as standard values from the OpenDSS transformer library.
- Loads and generators are considered to be connected to the low-voltage bus of transformers.
- There are very short lines corresponding to connection bars with lengths shorter than 1 m, so their impedance is very low. This produces convergence errors when calculating the power flow. Therefore, these very short lines were neglected, considering that the two bars are connected as a single bar.
- The capacitance of power lines was not provided by the distribution company. However, the effect of this parameter on underground lines can be significant. Therefore, a standard value is obtained for each project type.

3.4.3 Case base description

The considered base-case included simulations on two specific days: January 19, 2023 and July 14, 2023. During these two days, the electricity consumption was maximized due to the heating and cooling needs according to results from ECHO Clima (see section 2.1). Therefore, the simulation over these two days was considered the extreme case that could be produced in winter (for the first date) and summer (for the second one). The simulations were performed hourly for the entire day, and the hours in which the system situation was most critical were considered in detail. In particular, the maximum heating consumption during 2023

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was obtained on January 19 at 20:00, whereas the equivalent cooling consumption was obtained on July 14 at 14:00. Figure 35 shows the load profiles in both days for the base-case, considering the four CTs chosen for the scenarios (CT1, CT10, CT19 and CT158).

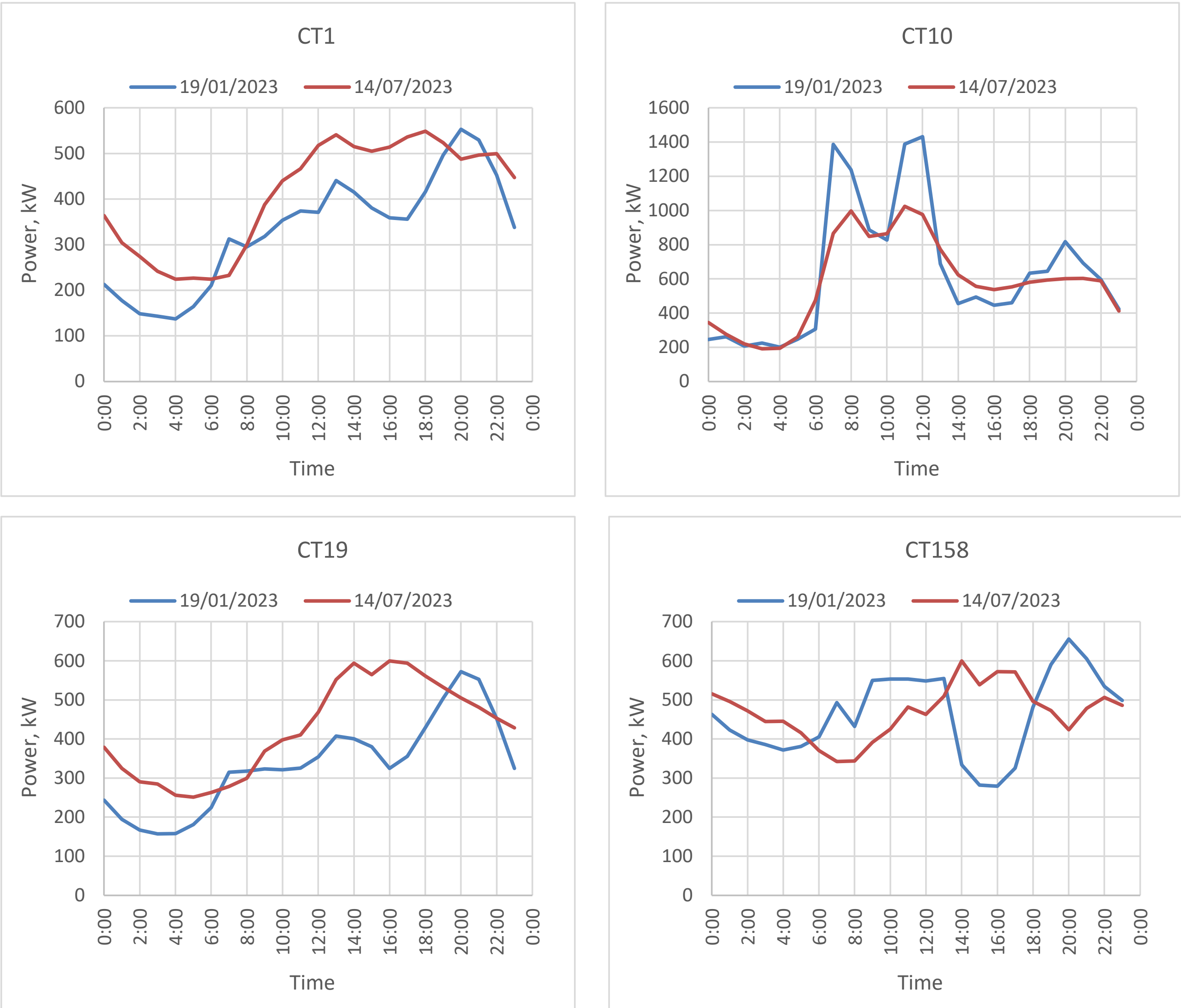

Figure 35 Load curves of chosen CTs for the base-case.

Results of simulations during these two days, represented graphically in Figure 36, show that there is not overload in any power line, and energy losses are not significant.

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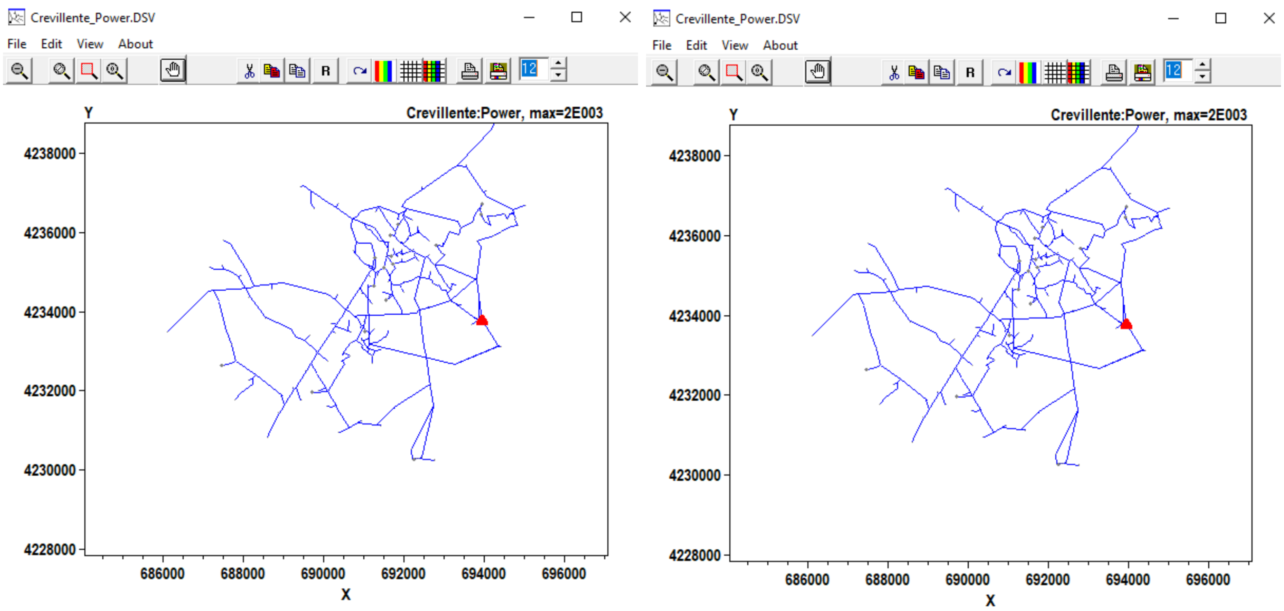

a) 19/01/2023 b) 14/07/2023

Figure 36 ECHO GRID simulations for the case base.

The point marked in red represents the location of the substation where the distribution grid is connected to the main power system (considered as slack bus for the model). On the other side, the thickness of the line in blue is proportional to the overload level. It means that thin lines indicate that the power through the considered element is below the nominal value, while the line turns thicker when the nominal power is overcome. Thus, it can be qualitatively understood as the thicker the line, the higher the power overload. Similarly, the higher the overload, the higher power losses as they are proportional to the square of the current through the line. The obtained results show as, in the present situation, the grid is well sized and it operates within appropriate security and efficiency levels.

3.4.4 Definition of scenarios

Flexibility services to solve operational issues in the distribution network

The electrical power system is currently under a significant transition toward a system with increased peak consumption and generation. This is mainly due to the electrification of transport and heating and cooling systems, as well as the rapid deployment of renewable energy resources connected at all voltage levels. This change in electricity generation and consumption patterns arises both from the urgent need to decarbonize the current global energy model and from the technological adaptation required to face new environmental, socioeconomic, and industrial challenges.

Accordingly, electricity distribution system operators are shifting toward a more dynamic participation in the electricity supply chain, moving from a passive participation, distributing electricity from the large electric generating units to the loads in the low-voltage network, to an expected active role in which decentralized generation of electricity flows in the opposite direction as previously, at low voltage levels and with high variability and intermittency due to the nature of renewable energy sources (such as solar or wind).

This new electricity paradigm entails a much more dynamic and complex management of the distribution network and the electricity system in general, leading to a greater number of congestion events and curtailments expected in the grid. The main issues observed in distribution networks are related to:

- Network congestion: Consumption or generation increase leading to electric current flowing through the system exceeding the operational limits of the distribution assets. For example,

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when fast EV charging points are operating simultaneously or with unpredicted fast heating and cooling electrification, these situations can lead to insufficient capacities of the cables and substations to cope with it at peak times.

- Voltage issues: When voltages exceed operational limits, for example, with the fast adoption of non-manageable renewable energy sources at residential and industrial scales (such as PV) connected to the LV network that typically have the same production pattern in a local area. This can lead to severe voltage deviations in distribution networks if reinforcement or flexibility measures are not in place.

To avoid these network problems, accelerate the deployment of distributed energy resources, and allow for faster transport and H&C decarbonization, DSO solutions can be realized by investing in new infrastructure and reinforcing the distribution network. Infrastructure upgrades can be very lengthy and costly. Therefore, a complementary and efficient solution based on the use of flexibility (from assets such as ECHO-TSS) is currently under technical and regulatory assessment all over Europe with the aim of using the untapped flexibility of network users to solve these issues and create a more efficient system.

As a result, DSOs are looking for different flexibility services to support the future complex management of distribution networks. The main solutions are the following:

1. <u>Non-firm (flexible) connection agreements</u>, defined by Article 24b of the new Market Design Directive (recast Directive) that amends Regulations (EU) 2019/943 and (EU) 2019/942 to improve the Union's electricity market design as: "a set of agreed conditions for connecting electrical capacity to the grid, that includes conditions to limit and control the electricity injection to and withdrawal from the transmission or distribution network". Connection agreements are always required for connecting to a DSO and these are given only when the capacity of the network can handle the maximum load or generation to be connected at any time. However, some of the assets being connected these days, EV chargers and PV systems mainly, can have a potential to be regulated (EV chargers) if the network cannot handle the demand at a specific point in time, or to be curtailed (PV systems) in case of a network issue arises, for example at the highest production months the production could be reduced to avoid network issues while the rest of the year it could be producing at the maximum power. Currently, connection would only be granted if a reinforcement is completed, which can take years of delays.
2. <u>Local flexibility markets</u> consist of the acquisition of flexibility services by DSOs through local market mechanisms aimed at improving the management of congestions in the operation of distribution networks. Instead of curtailing consumption or generation, an alternative option for the DSO would be to purchase flexibility in an open market to support the network when required or to delay potential reinforcements. Economic analysis by DSOs is still required to identify under which conditions the provision of flexibility can represent a better alternative to typical investments in grid reinforcements. These markets need to be design appropriately to increase the participation from smaller resources as opposed to traditional balancing markets in which only very large consumers can participate.

Flexibility assets need to be able to dynamically vary demand or generation in response to network issues, for example, energy storage systems (such as ECHO-TSS) that provide flexibility by charging and discharging storage systems as required by the electricity network. It is expected that any type of flexibility source can participate in flexibility markets (technology neutral and non-discriminatory) as long as it complies with the product requirements specified by the DSO for each individual issue.

The use of flexibility in any form by DSOs will lead to cost reductions for final electricity users and to better quality of service, which is a priority for DSOs. This will also allow the development of new businesses in the

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provision of energy services for final consumers and users of the electricity system, such as tools to manage energy consumption and generation more efficiently.

Flexibility markets for ECHO-TSS participation

Consumers with energy storage solutions such as the ECHO-TSS will have the opportunity to participate in local flexibility markets individually or through an aggregator. Flexibility markets can be used to solve different types of issues in the network and at different timescales, accordingly the market types could be divided in short- and long-term markets.

The long-term flexibility market will be used to procure flexibility while network reinforcements (with lengthy processes to be operational) are being implemented for solving known network issues or for supporting any planned maintenance that can suppose a congestion in the grid of the network. The provision of this type of flexibility will typically be done for large periods of time (months or years), although the flexibility might only be occasionally activated. Therefore, it is expected that economic bids from flexibility providers in long-term markets can be based on two main price components, although depending on the product the payment structure might have only one of these components, these are:

- Availability price: The flexibility providers will be paid for having the contracted energy amount available at the predefined times agreed with the DSO and with an agreed availability price.
- Activation price: This is the price that the DSO will pay to the flexibility providers for the activation and provision of the contracted energy for a period of time communicated by the DSO and according to the agreement.

The short-term market is a faster and simple flexibility market that can be triggered when an unplanned event or congestion is predicted to be happening within a short period of time and the procurement for this product will be done in a day-ahead market.

The costs of flexibility procurement need to be such that the DSO finds a benefit by using flexibility instead of developing new infrastructure or using other alternatives (i.e. diesel backup generators) while simultaneously allowing the development of feasible business models for flexibility providers.

Local flexibility markets are still in a pilot phase in most European countries, lacking regulatory frameworks and commercial deployment, resulting in a limited number of examples that can identify potential economic revenues. Nonetheless, the UK is one of the countries with a flexible market in operation in some DSOs, but it is still in the early stages, leading to high uncertainties regarding the prices that these services can have, as prices can vary vastly when considering different DSOs, zones, or products within each DSO. As an example, figures from the Autumn 2023 tender of UKPN[1] can be obtained at their tender hub, from which the average fees agreed for their flexible products are shown in Table 5. In the example, it is evidenced the so different prices according to the kind of flexibility service provided. Moreover, it is illustrated as concepts payed to participants may vary significantly, from capacity or availability payments (where participants are payed for their availability even if they are not finally requested to activate their flexibility) to incentives in exchange for flexibility actually used:

Table 5 Average fees for flexibility products in the Autumn 2023 tender of UKPN.

Product	Average Capacity (MW)	Average Availability Fee (£/MW/h)	Average Utilisation Fee (£/MWh)	Average Service Fee (£/kW/season)	Average Maximum runtime (h)
Secure	0.13	177.77	279.15		2.55
Dynamic	1.52		156.00		
Sustain	0.03			30.62	4.25

where the products are defined by UKPN in (UK Power Networks, 2023) as:

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- Secure: “Flex providers are paid an Availability Fee to be available for set time windows in set seasons, and then a Utilisation Fee when dispatched (via day ahead dispatch)”
- Dynamic: “At day ahead, when requested, flex providers confirm available capacity and price, and are paid a Utilisation Fee when dispatched (via day ahead dispatch)”
- Sustain: “Flex providers agree to reduce peak load for set time windows in set seasons in return for a Service Fee”

Similarly, from the statistics of the PICLO[7] UK flexibility marketplace in Table 6, similar average prices can be observed for the availability and utilisation competition type (similar to the Secure product in Table 5), but for the competition type only with utilisation type a much cheaper price is observed.

Table **6**. Average prices for flexibility products of the PICLO UK flexibility marketplace

Competition Type	Availability Guide Price (£/MW/h)	Utilisation Guide Price (£/MWh)
Availability utilisation	149.31	238.79
Utilisation	0.00	51.89

Definition of the scope for the case study: consumers clustering and characterization

The performed study has considered increments of demand in four transformation centres, which are composed of different types of consumers according to a diverse rate. Due to the particular characteristics of this specific grid, most of consumers are residential, but there are also some industrial and commercial consumers, as well as offices and public services. The location of these four transformation centres is indicated in Figure 37 by a yellow star.

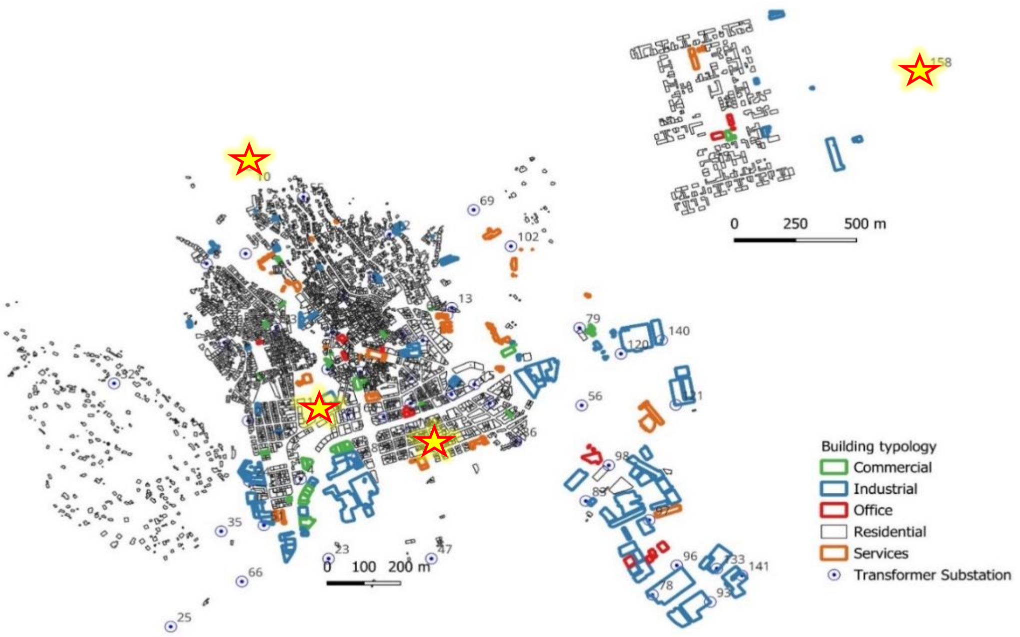

Figure 37 Location of the chosen transformation centres for definition of scenarios.

The considered centres were:

[7] https://data.piclo.energy/

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- CT1 (RAMBLA 1). It includes 90 residential buildings and 2 industries.
- CT10 (GINES). It is composed of 103 residential consumers and 2 industries.
- CT19 (RONDA SUR). 103 residential consumers plus 3 public services facilities are connected to this centre.
- CT158 (EL SALA): Finally, this transformation centre includes 90 residential consumers, 5 industries, 3 offices buildings, 1 public service and 1 commercial building.

Definition of management strategies for ECHO-TSS users

In addition to the base case described before, four scenarios have been considered in order to perform a sensitivity analysis regarding the increment in the power demand produced by the increment of electricity consumption due to acclimatisation end uses in summer and winter. These scenarios have been defined as follows:

- Scenario 1: increment of demand due to growing ambient temperature due to the climatic change.
- Scenario 2: increment of 25% of electric demand due to a medium growing of electric needs due to acclimatisation end uses.
- Scenario 3: increment of 50% of electric demand due to a large growing of electric needs due to acclimatisation end uses.
- Scenario 4: increment of 75% of electric demand due to a very large growing of electric needs due to acclimatisation end uses.

Thus, an increment of load in three steps (25%, 50% and 75%) has been simulated in a winter typical day to consider a higher demand due to electric heating with heat pump. Similarly, an increment of load in the same three steps has been considered in a summer typical day to take into account a higher demand due to the air conditioning.

Typical days for summer and winter have been the same as considered for the case base: 19 January 2023 for winter and 14 July 2023 for summer, which are those with the maximum consumption due to heating and cooling according to results from EUReCA project (see section 2.1).

3.4.5 Preliminary results

a) Scenario 1

In this scenario, an extra demand was added into transformation centres CT1, CT10, CT19 and CT158 due to higher temperatures in a climatic change scenario. Modified load curves according to that scenario have been obtained from the EUReCA model, as explained in section 2.3.4 .Figure 38 represents the situation of the grid for the most critical day of the considered days, which corresponds to 19/01/2023 at 4:00 and 14/07/2023 at 10:00. The red dot shows the location of the substation (connection to the main electricity grid and slack bus for simulation purposes).

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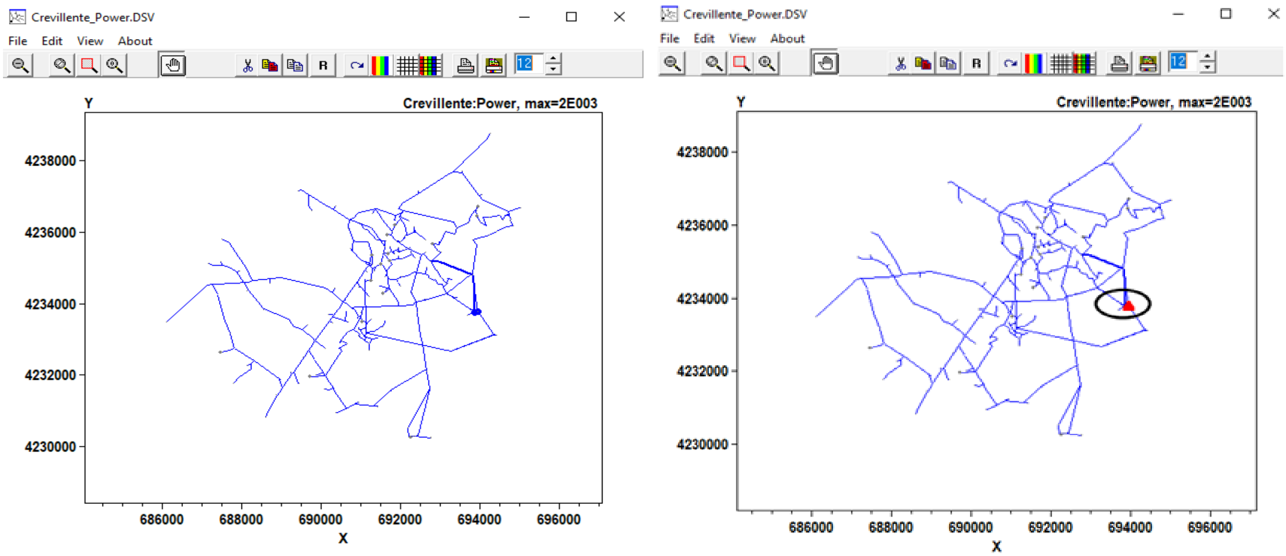

a) 19/01/2023, 4:00 b) 14/07/2023, 10:00

Figure 38 ECHO GRID simulation for the Scenario 1

Overloads are produced in three power lines (denoted by the numbers 499, 2452 and 2762 and marked by a thick blue line in Figure 38. The maximum overload would be produced in line 2762, equivalent to 168 kW in winter and 269 kW in summer. The maximum daily overload per line is shown in Table 7.

Table 7 Overloaded power lines and overload magnitude in Scenario 1

Power line				Winter		Summer	
Code	Type	Nominal voltage	Nominal power	19/01/2023, 4:00h		14/07/2023, 10:00 h	
				Overload		Overload	
		kV	*kVA*	*kW*	*%*	*kW*	*%*
499	Aerial	20	10,843	151.3	1.7%	262.8	3.0%
2452	Aerial	20	6,928	135.7	2.4%	235.2	4.2%
2762	Undergrown	20	15,415	168.1	1.4%	269.2	2.2%

In this scenario, the maximum overload in all cases is always lower than 5%, assuming a power factor of 0.8.

b) Scenario 2

This scenario foresees and increases of 25% for the power demand on transformation centres CT1, CT10, CT19 and CT158 in order to evaluate the capacity of the grid to manage additional loads due to acclimatization end uses and so, evaluate potential overloaded areas. The most critical situation (maximum overload) in winter and summer is represented in Figure 39.

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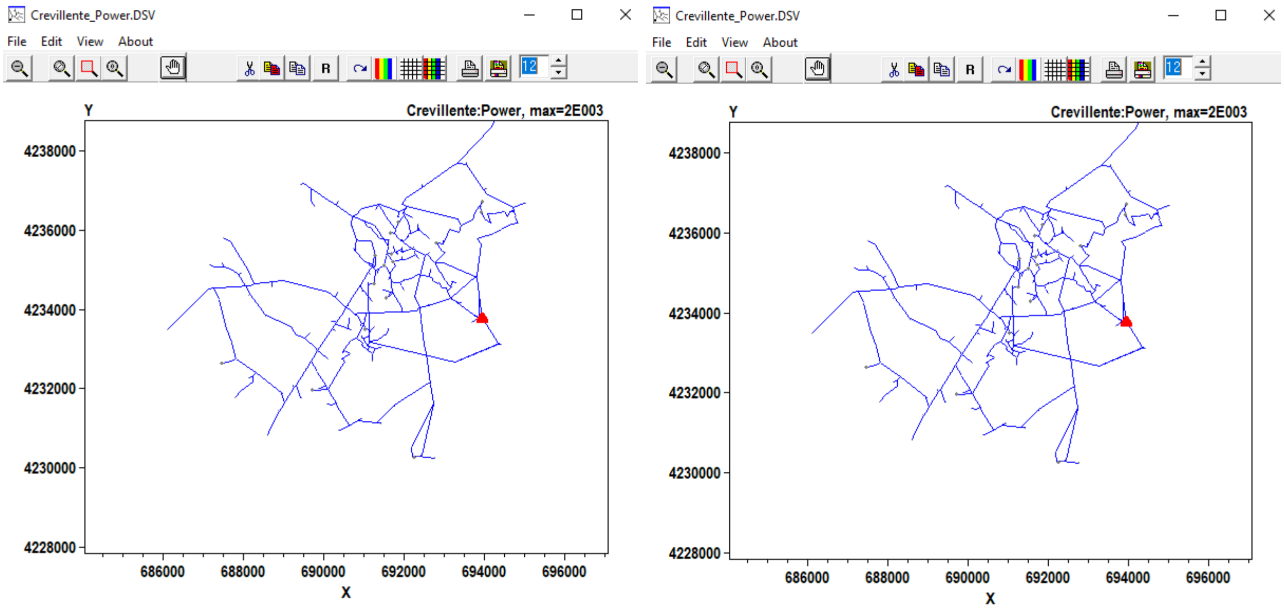


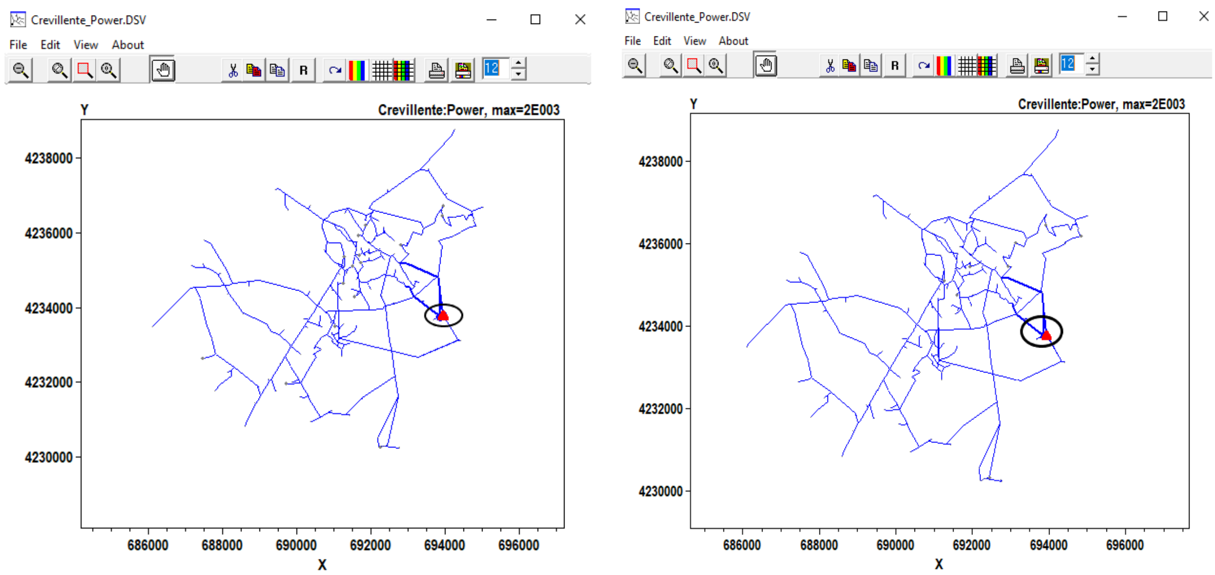
a) 19/01/2023, 9:00 b) 14/07/2023, 10:00

Figure 39 ECHO GRID simulation for the Scenario 2

As in the previous scenario, the thickness of the lines represents the load throughout each of them. In this case, the 25% increase in the demand does not saturate any of the power lines of the system, thus the grid would be able to satisfy the demand without operational problems in this case.

c) Scenario 3

In this scenario, a 50% increase in the power demand on transformation centres CT1, CT10, CT19 and CT158 is considered. The increment of 50% of demand entails a substantial overload in power lines 2762, 2737, 499 and 2452 in this order. The highest overload is produced in line 2762, as shown in Figure 40.



a) 19/01/2023, 9:00 b) 14/07/2023, 10:00

Figure 40 ECHO GRID simulation for the Scenario 3

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In both cases, winter and summer, the maximum overload takes place in the morning (9:00 in winter and 10:00 in summer). The maximum overload would be produced in line 2452, equivalent to 281 kW in winter and approximately the same in summer. The maximum daily overload per line is shown in Table 8.

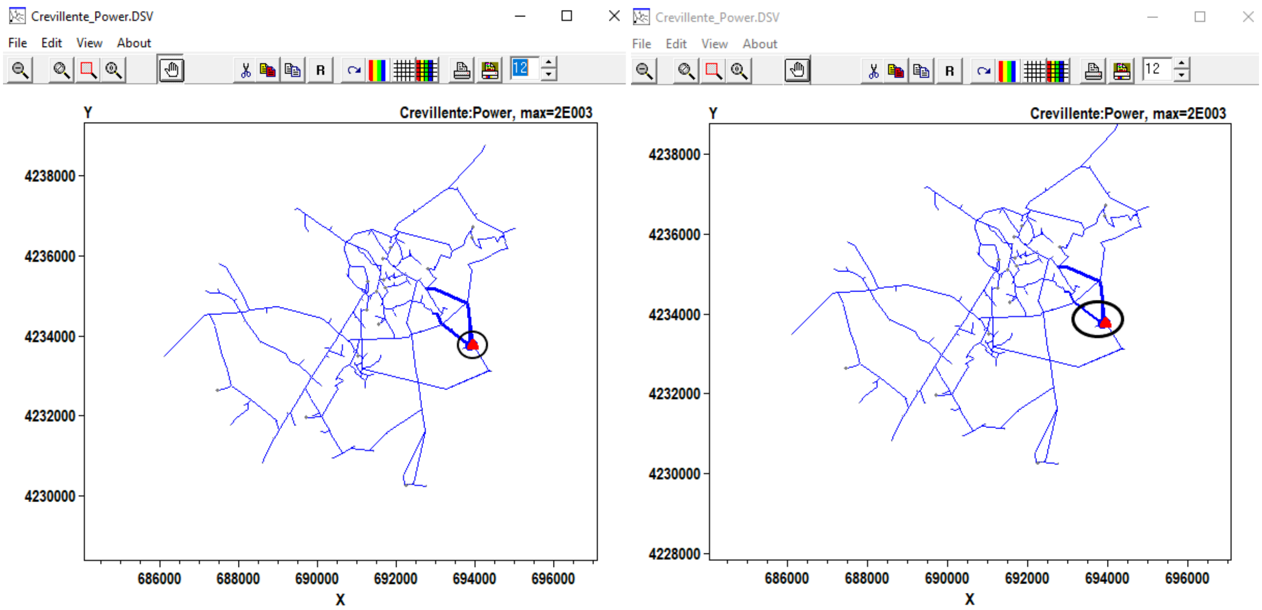
Table 8 Overloaded power lines and overload magnitude in Scenario 3

Power line				Winter		Summer	
				19/01/2023, 9:00h		14/07/2023, 10:00 h	
Code	Type	Nominal voltage	Nominal power	Overload		Overload	
		kV	kVA	kW	%	kW	%
499	Aerial	20	10,843	212.3	2.4%	222.1	2.6%
2452	Aerial	20	6,928	280.5	5.1%	280.9	5.1%
2762	Underground	20	15,415	206.3	1.7%	210.9	1.7%
2737	Underground	20	15,415	34.7	0.3%	58.2	0.5%

In this scenario, the maximum overload reaches 5% in power line 2452 in summer and winter. The rest of values remain under 3%, assuming a power factor of 0.8.

d) Scenario 4

An increase of 75% of the power demand on transformation centres CT1, CT10, CT19 and CT158 is simulated. In this case, power lines 499, 2452, 2737 and 2762 present an overload, as evidenced in Figure 41.



a) 19/01/2023, 2:00

b) 14/07/2023, 10:00

Figure 41. ECHO GRID simulation for the Scenario 4

As it is shown in Table 9, the maximum overload happens in power line 2765 at 10:00 in summer, with an overload of 363 kW, assuming a power factor of 0.8.

Table 9 Overloaded power lines and overload magnitude in Scenario 4

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Power line				Winter		Summer	
Code	Type	Nominal voltage	Nominal power	19/01/2023, 2:00h		14/07/2023, 10:00 h	
				Overload		Overload	
		kV	kVA	kW	%	kW	%
499	Aerial	20	10,843	242.7	2.8%	291.6	3.4%
2452	Aerial	20	6,928	342.0	6.2%	343.7	6.2%
2762	Underground	20	15,415	355.5	2.9%	362.7	2.9%
2737	Underground	20	15,415	99.1	0.8%	98.0	0.8%

Proposed solution with ECHO-TSS devices to manage technical constraints

ECHO-TSS devices can provide flexibility to the power grid in the sense that energy can be stored when the system is in surplus (e.g. when there is an excess of photovoltaic production which may overload some electric infrastructure), and it can be delivered when the system is in deficit. In this way, the ECHO-TSS device absorbs electricity from the grid, but it does not deliver electricity but heat, so that the electricity consumption that is reduced should be understood as the electricity that heat pumps do not consume due to the heat provided by the thermal storage system. As a matter of illustration of the ECHO-TSS concept, we have simulated the activation of the ECHO virtual battery to help solving the maximum overload produced in Scenario 4 during January 19, 2023, when this overload was maximum. Figure 40 shows the daily profile of the 2762 overload.

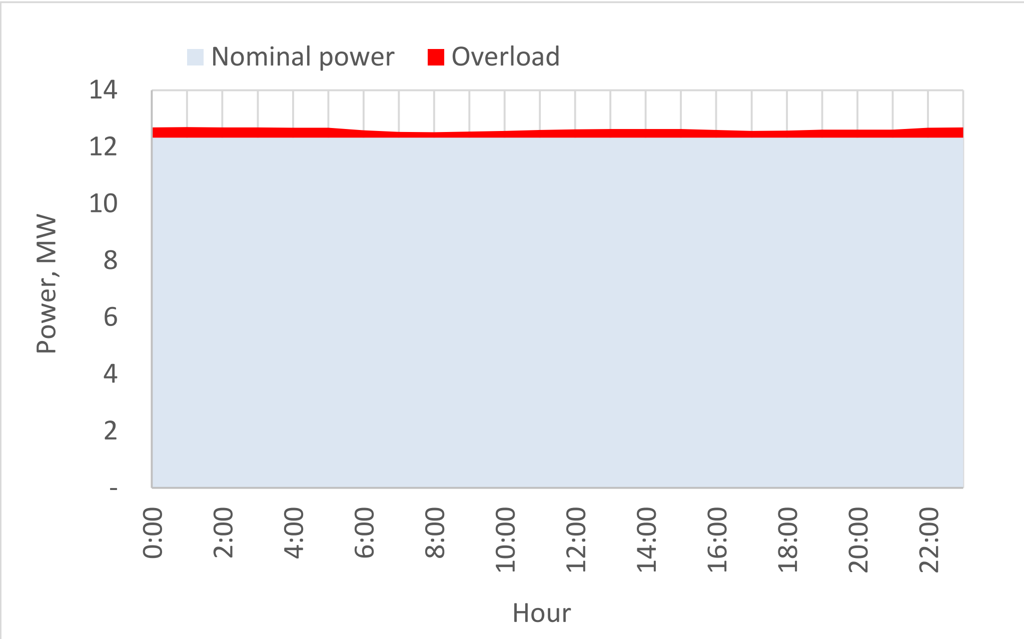

Figure 42. Hourly load profile in line 2672 for the Scenario 4 on 19 January 2023

The profile of currents is shown in Figure 43, where the nominal value of 445 A is overloaded in all the hours.

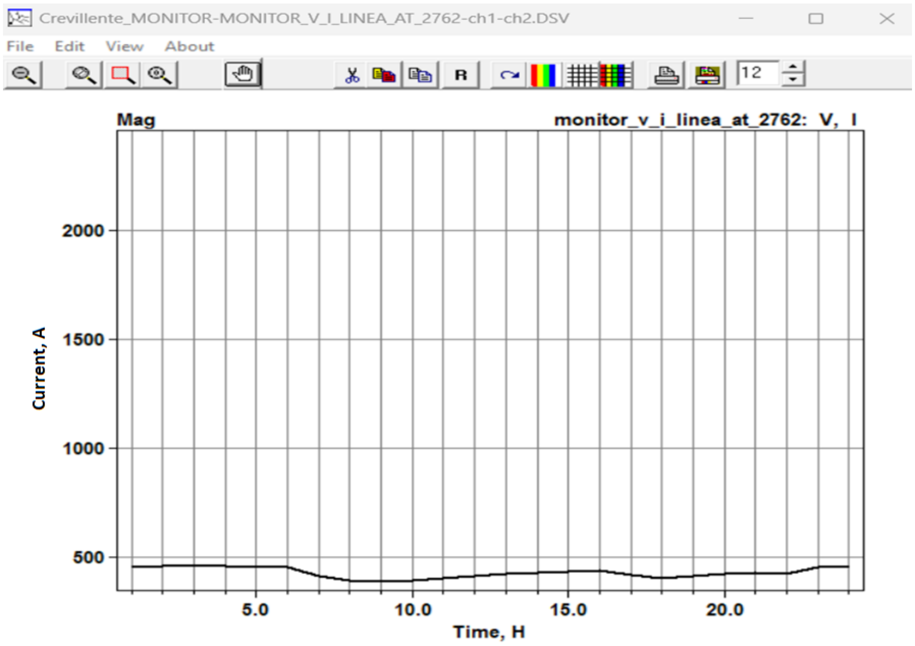

Figure 43. Current profile in line 2672 for the Scenario 4

The considered hypotheses to perform this evaluation are the following:

- ECHO-TSS devices will be placed on the buses where the increment of load for the Scenario 4 have been produced, that are the transformation centres CT1, CT10, CT19 and CT158.
- ECHO-TSS devices will have a storage capacity equivalent to the energy that overloads the power line during the day 19 January 2023 (that is the area below the curve represented in Figure 44).
- The capacity storage for an ECHO-TSS unit is considered equivalent to be equal to 3 kW_e maintaining the heat at this rate for at least 1 day. It means that during the day when the overload has been produced, the ECHO-TSS unit will be able to supply the thermal energy that is usually produced by heat pumps and, therefore, reduce the electricity that would be overloading the power line. After that, during the following days, the ECHO-TSS would be charged again consuming electricity when the power line is not overloaded.

The amount of energy overloading the line during the chosen day is:

$$E_{stored} = \int_{0:00}^{23:59} P_{overload}(t) \cdot dt \qquad (3.12)$$

where $P_{overload}(t)$ is the value of aggregated overload curve for the period *t*. The total overload that occurs in the four power lines mentioned in Table 9 is shown in Figure 44, where the maximum aggregated overload is produced at 2:00, reaching 1,049 kW.

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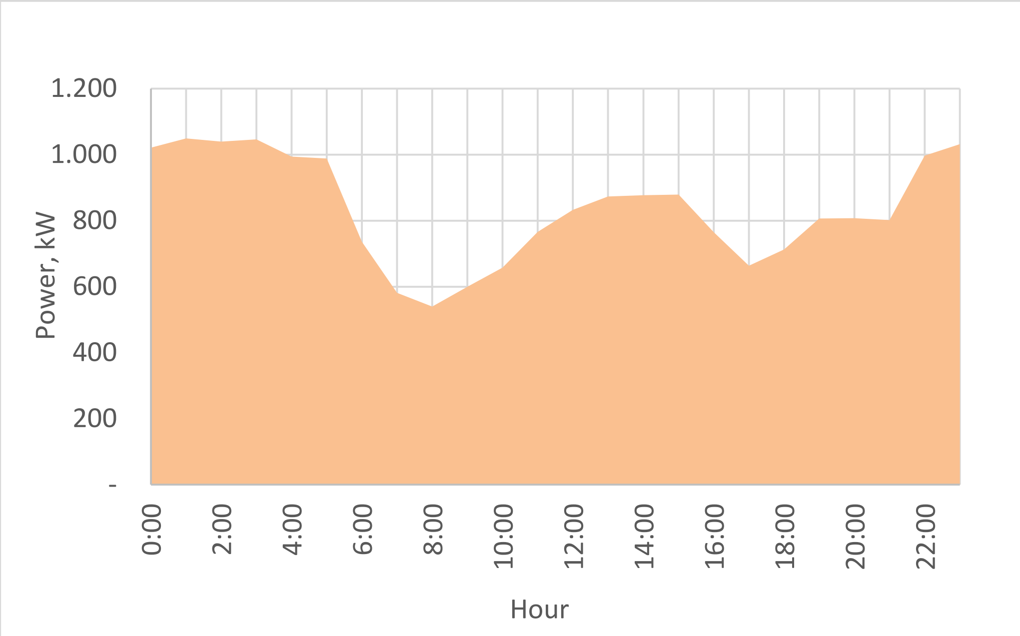

Figure 44. Aggregated overload produced in power lines 499, 2452, 2762 and 2737 for the Scenario 4

Therefore, E_{stored} corresponds to the area below the aggregated overload curve, which is equal to 20,065 kWh. The average overload during the day would be calculated according to the following expression:

$$P_{overload}^{mean} = \frac{E_{stored}}{24} \quad (3.13)$$

According to this expression, the average overload during this day would be equal to 836 kW.

Considering that 1 ECHO-TSS unit is able to supply the stored heat at the nominal rated power for, at least, 1 day, the number of ECHO-TSS units of 3 kW_e that would be necessary to evacuate the energy overloading the four power lines would be calculated as follows:

$$N_{ECHO-TSS} = \frac{P_{overload}^{mean}}{P_{ECHO-TSS}^{UNIT}} \quad (3.14)$$

Therefore, the number of units to reduce completely the maximum mean overload would be equal to 279. ECHO-TSS units have been distributed among CT1, CT10, CT19 and CT158 proportionally to the number of residential consumers on each transformation centre, resulting as follows:

- CT1: 65 ECHO-TSS units (90 residential consumers)
- CT10: 74 ECHO-TSS units (103 residential consumers)
- CT19: 74 ECHO-TSS units (103 residential consumers)
- CT158: 65 ECHO-TSS units (90 residential consumers)

According to this distribution, 72% of residential consumers would be required to have an ECHO-TSS installed at their facilities providing this service. Storage appliances for residential and commercial customers have been neglected. A new power flow simulation was performed by reducing the load in the four CTs according to the number of ECHO-TSS delivering thermal energy during the day when the four lines were overloaded; the result is shown in Figure 43. As can be seen, the final load after activation of the ECHO-TSS system was significantly lower than the initial load. The overload was reduced to a maximum value below 1%; however,

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during the valley period, the power through the power lines remained below the nominal power during the peak period. This result highlights the ability of ECHO-TSS devices to solve operational issues in the distribution grid, depending on the benefits of the devices' users when providing such services based on incentives and price signals to be produced by a potential flexibility market, as discussed in the next section.

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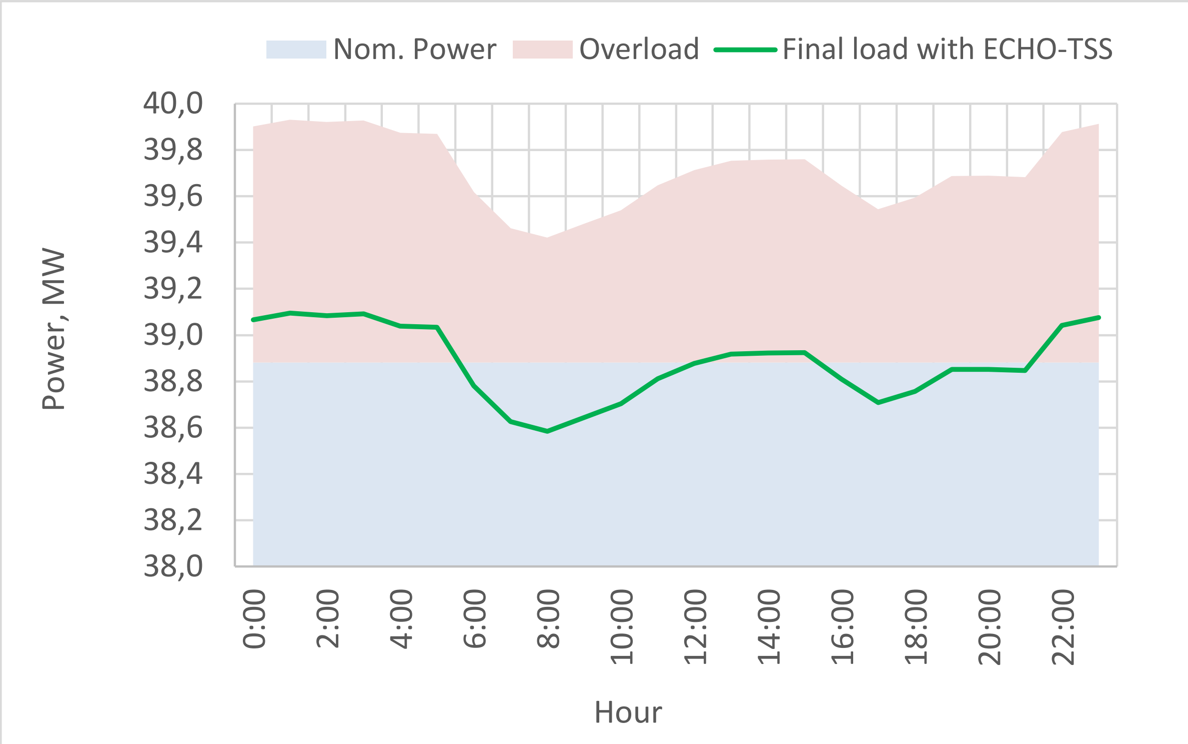

Figure 45. Aggregated load curve in power lines 499, 2452, 2762 and 2737 after and before installing the ECHO-TSS devices according to the Scenario 4

In order to be used to deliver thermal energy to consumers during the critical day, it is requested that the ECHO-TSS devices charge during the previous days. Therefore, a new simulation has been done so as to analyse the impact in the grid. Due to the lack of detailed information about the specifications of the ECHO-TSS device at this stage of the project, the following hypothesis have been considered:

- A performance of 90% has been considered, that means the electric energy necessary to charge the ECHO-TSS devices is 10% higher than the electric energy that is not consumed when the ECHO-TSS unit delivers the stored thermal energy.
- ECHO-TSS devices are completely discharged four days before the critical day
- Devices are charged during three days (D-4, D-3 and D-2). D-1 there is neither charge nor discharge since the load starts growing during such day. Finally, during the day D, all devices are discharged simultaneously.
- Charge of ECHO-TSS devices takes place staggered, so that an average power is maintained almost constant during the three days when the devices are in charge.

According to these hypotheses, the following results are obtained:

- Electric energy reduced during the day of activation of flexibility (19/01/2023) is 20,065 kWh. Therefore, the electric energy required to charge the storage devices is 22,295 kWh.
- The capacity of one device is 80 kWh. Therefore, one device needs about 27 hours to be completely charged.

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- The mean extra power due to the charge of devices is 310 kW.
- During the three days of charge, the line overload remains under 1% of the nominal power of the lines.

The load curve of the mentioned consecutive five days, where the nominal power, the overload and the final power considering the charge and discharge of ECHO-TSS devices according to Scenario 4 are depicted, is shown in Figure 46.

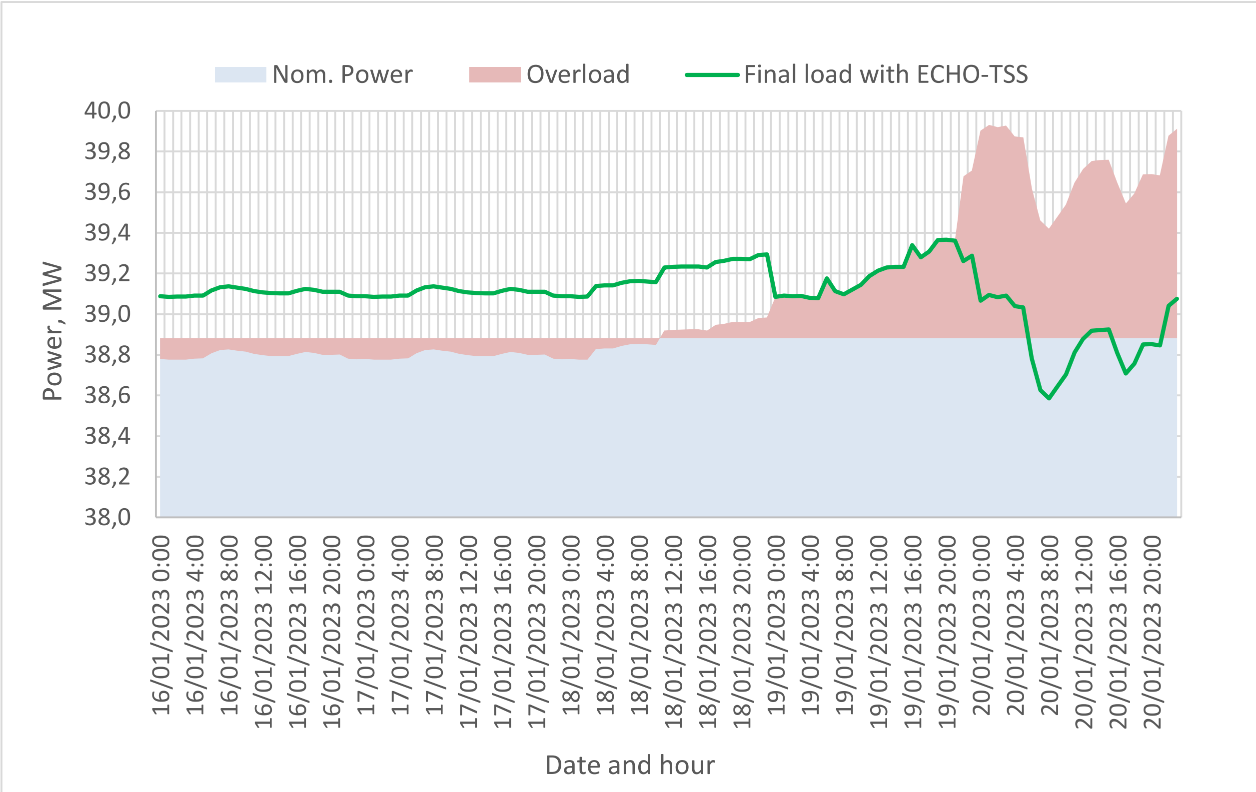

Figure 46. Aggregated load curve in power lines 499, 2452, 2762 and 2737 considering the charge and discharge of the ECHO-TSS devices according to the Scenario 4

4 ECHO-CLOUD

4.1 General description

The fundamental contribution made by ECHO-CLOUD to the ECHO project is to enable the aggregation of the state and consumption that various ECHO-TSS devices can perform at specific times of the day and provide this information to facilitate interaction between users and electricity distribution companies.

This interaction aims to enable, in a simple and automatic way, the participation of these agents in a local-scale demand flexibility market for electricity consumption and to promote the use of local Smart Grids.

Local Smart Grids are a crucial component in the European Union's energy and decarbonization strategy, as these strategies promote the integration of renewable energies, energy efficiency, and grid stability. At the same time, they empower domestic prosumers, enabling them to manage their energy more efficiently,

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participate in flexibility markets, and reduce their energy costs, thus contributing to a more sustainable and equitable energy transition.

The local nature of these types of grids favors the rational sizing of electricity production since the needs of a particular area (municipality, group of municipalities, or region, for example) can be calculated more accurately and in advance.

With the inclusion of ECHO-CLOUD, the ECHOTSS platform allows each ECHO device to act as an aggregation agent that allows the servers of the ECHO-CLOUD platform to construct a Virtual Battery that displays the aggregated storage capacity of the sum of all ECHO-TSS devices connected at a given moment. Additionally, the ECHO-CLOUD system maintains an individual activity log for each ECHO-TSS device to perform the relevant control operations.

This mode of operation enables ECHO-TSS users to participate in flexibility markets where local electricity distributors operate by offering energy storage services and demand management in exchange for economic incentives related to the discount of their electricity consumption cost.

To achieve this purpose effectively, ECHO-CLOUD features a common environment for generating and managing digital Smart Contracts, simplifying the interaction between prosumers and electricity distributors in an electricity demand flexibility market.

For **users**, it provides a mechanism to access information on flexibility offers and empowers the prosumer as a fundamental agent in making rational use decisions of the electrical system through a price incentive system. It also provides a means to verify the billing and control of the electricity consumption activity for heating purposes reliably. Finally, by fulfilling the contractual conditions, these Smart Contracts become an additional source of income in the form of bonuses or discounts for the user of an ECHO-TSS.

For **electricity distributors**, it offers a dual perspective. On one hand, it displays the aggregated individual storage capacity as a Virtual Battery that allows them to calculate the aggregated capacity available at a given moment to perform a consumption balance that helps stabilizing the grid by participating in ECHO-CLOUD.

Stabilizing the electrical grid through consumption balance is one of the most efficient mechanisms to achieve a resilient electrical grid that democratizes the participation of the different agents involved and is also a system that significantly saves the costly investments implied by the redundancy and oversizing of a traditional centralized electrical distribution grid.

4.2 Components

This document describes the software components that constitute the data exchange system between the ECHO-TSS devices and a computer system for aggregating this information, as well as the complementary components for its operation.

The purpose of these components is to develop a computer utility that allows establishing an electric demand flexibility market that allows the electric power distributor to offer remuneration plans to end users if they make the electricity consumption related to the thermal use of its installation at the schedules established by the distributor.

The following description obeys a functional criterion that describes the operational logic of the system and not the chronological order of the development of the different components described.

In this phase the JSON format for data structuring and Rest architecture is used to offer an API to exchange this data between the different software components.

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Components in the electronic control device installed in the ECHO-TSS device

Note: It is assumed that the electronic control device installed in Echo-PSS follows the SCADA standard, (Supervisory Control and Data Acquisition). We will call this electronic device, Echo Scada Device, abbreviated ESD.

In the ESD, the communication software component between the ESD and the servers that carry out the aggregate operations and offer flexibility services must be installed as standard. This component performs two basic functions:

a.- The secure connection between the ESD and the servers that offer flexibility services.

b.- Sending data from the ESD to the flexibility servers.

Connection between the ESD and ECHO-CLOUD servers

A secure connection must be established between the ESD and the flexibility servers. To do this, the ESD must integrate the configuration of the session validation services with the servers to generate the session token and start the communication channel.

Sending data from the ESD to the flexibility servers

Once a security token is established and the channel is validated, data sending begins automatically.

To do this, the ESD must integrate a specific data sending and writing service method and incorporate a conversion system for the electronic signals corresponding to the service parameters.

The minimum data set that will send to the servers is the following:

- Echo TSS device identification
- Identification of the Echo TSS Device holder
- Echo TSS device status
- Remaining load capacity of the Echo TSS device
- Moment in which data is carried out.

Components on the electronic control device installed on Echo-Cloud flexibility servers

Participant Registration Component

The servers will have a service that allows different participants, through a secure Web interface, to register to participate in the demand flexibility market.

Two types of registration are contemplated depending on the role played in the electricity demand flexibility contract:

- **Registration of electrical distributor:** They must enter their identification data. In this process they will receive security credentials that will allow them to operate with the system and access the functions that are allowed, especially those of introduction of offers and consumption state consultation
- **Registration of bidders (holders of an ESD):** they must enter their identification data and those of their ECHO TSS devices. They will automatically assign security credentials, although at a later time and after a first successful session they can introduce some generated by them. With these credentials they can accept participating in flexibility offers and consulting the status of their activity.

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Smart contract component

The contracting of remuneration for services to flexible the demand for electricity consumption is carried out through two separated but connected registers.

What is actually contracted, that is, the object of the contract, is that the user's electrical consumption destined for thermal purposes is carried out at the times indicated by the distributor, using for this purpose the capacity of the ECHO TSS devices to temporarily decouple the electrical consumption and functional use (consuming electricity at one time and using heating or cooling functions at a later time), and not actual storage of electricity.

The component contemplates the possibility of establishing a penalty for those consumptions that are outside the established hours or leaving this consumption neutral with respect to market prices.

Registration of economic offers for the use of ECHO-TSS capabilities

Registered Flexibility Services Claimants may indicate the incentive to program the ECHO TSS to consume electricity in a specific time slot and for a specific period.

Acceptance of offers

ECHO-TSS bidders accept the offer for a certain period or in the conditions established.

Compliance condition

The ESD whose consumption is made in the remunerated schedules, are those that form the virtual battery (VB) and its consumption will be encouraged by the discount or economic offer that the distributor deems appropriate. Otherwise, that is, if it is not consumed in the schedules and quantities, the information is collected, but is not part of the VB.

Produced compliance or not, the distributor will carry out the commercial operations that have been agreed with the user.

Aggregate Component (Virtual Battery)

This component collects the information that each ESD sends and generates the VB.

The VB does not represent a direct system of accumulation of a quantity of energy itself, but rather a capacity to use the individual storages recorded by the ESDs to provide a consumption control system that allows for a displacement of that consumption through incentives (discounts) offered by the electricity supplier.

This information represents the amount of electricity consumption that has been managed to shift to a specific time slot during a specific period.

To establish the criteria for use, ECHO-CLOUD assumes control of the following parameters:

- Standard electrical consumption for thermal purposes of the user to determine the behavior pattern of the ECHO-TSS device.
- Electrical supply needs for thermal use of the buildings in which the ECHO TSS device is installed. This data will be used to establish behavioral thresholds and predictive capacity. For this calculation, the metrics and systems developed by the UPV.
- Capacities and needs of the electrical supply network to establish control thresholds that are related to seasonality. This information will be based on the results provided by the UPV.

Operations Query Component

The operations that generate the VB are not directly accessible by the participants.

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To access this information, the bidder participants (consumers) must initiate a safe session using the security credentials assigned to it in the Register of ESD. The information that will be displayed will be the particularized activity of the ECHO TSS of those who are holders. This information will indicate the amount of electricity consumed during paid periods. By transparency, information regarding consumption periods in unpaid - periods will also be included.

For flexibility plaintiffs (distributors), both aggregate and disaggregated information of user consumption will be offered.

The aggregate information will allow to see the global behavior of the system to achieve the objective of effectively displacing the demand in its network. On the other hand, disaggregated information will allow commercial bonus or penalty operations to be carried out between the contracting parties.

4.3 ECHO-CLOUD Operation

The operation of ECHO-CLOUD is designed to facilitate the automatic matching of supply and demand in a market for flexible electricity consumption once the conditions agreed upon by both parties are accepted. This is achieved through the interaction between ECHO-TSS devices and the ECHO-CLOUD platform.

4.3.1 From the Perspective of the Flexibility Seeker (Electricity Distributor)

Necessary Equipment

To register offers associated with changes in electricity consumption habits for climatization by potential clients, the electricity distributor must have a computer configured to access the Internet.

Operation

For an electricity distributor to operate within the flexibility market and register offers that incentivize electricity consumption for climatization during preferred time slots, the distributor must:

- Register on the ECHO-CLOUD platform through the supplier registration application. Access to this application is provided via a web interface.
- After registering the identification data, they will receive a confirmation providing access credentials to the system.
- Once logged in, they can register bonus offers for consumption that occurs during preferred hours using ECHO-TSS devices.
- Optionally, they can also specify time slots during which consumption via ECHO-TSS devices, as verified by ECHO-CLOUD, will incur penalties.

The final mode of contract operation will depend, in part, on the observations noted at the end of this section.

Through the web interface, they can access a suite of tools to monitor and verify the activity and progress of their contracts and consumptions, both individually for billing control and in aggregate to monitor the impact on consumption shifts according to their objectives for demand flexibility based on the needs of their electrical grid.

4.3.2 From the Perspective of the Flexibility Supplier (User with an ECHO-TSS)

Necessary Equipment

To connect an ECHO-TSS installation with ECHO-CLOUD, a router connected to the general Internet is required, connecting to the ECHO-TSS control device via an RJ45 physical interface and the Ethernet frame

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standard for data transfer. Currently, this type of equipment is common in European SOHO environments and is, in fact, standard.

Additionally, to accept offers associated with changes in electricity consumption habits for climatization, the user of an ECHO-TSS must have a computer configured to access the Internet.

Operation

- Register as a user on the ECHO-CLOUD platform so that the ECHO-TSS device can operate within the flexibility market.
- Accept one of the consumption offers listed on the platform.
- Once accepted, the ECHO-CLOUD platform will receive readings from the ECHO-TSS control device, determining the times of consumption.

Secondly, the user must accept the conditions set by the electricity distributor. Once acceptance is completed, bonuses or penalties will be assigned based on verified consumption.

NOTE: Depending on the capabilities ultimately installed in the control device, contract acceptance may operate in various ways. The simplest method is to evaluate post-consumption activity and apply the economic incentives or penalties established for specific time slots. Alternatively, the system could automatically enforce ECHO-TSS electricity consumption during certain time slots, allowing the user to consume at different times for climatization needs, optionally penalizing these periods or keeping them economically neutral.

4.3.3 Simulation of Results

Two important factors need to be taken into account: the fact that the project will only include the installation of 4 demonstrators of the physical ECHO-TSS devices, which is quantitatively insufficient to carry out adequate aggregation operations for a local-scale electricity demand flexibility market, and that these devices will be located in areas that are not climatically homogeneous, which will significantly alter the usage patterns of the climatization devices.

Considering the aforementioned factors, a simulation of the ECHO-CLOUD system operation will be provided using data obtained from the analysis of the city of Crevillente, contributed by other project partners. Similarly, the methodologies and analytical models introduced will be those indicated in the preceding chapters of this document related to consumption and installation modelling, also pertaining to Crevillente.

5 Scenarios analysis and spatial application by means of GIS

The objective of the analysis scenario is to assess the potential impact of incorporating a TES device combined with smart control. This integration aims to reach a critical mass of demand, analysing the potential of flexibility to mitigate electrical grid overload ensuring a more stable and sustainable energy system and facilitating the shift of the local energy mix towards a greater inclusion of local renewable electricity (RES) in various scenarios. Furthermore, the potential of flexibility to mitigate electrical grid overload will be assessed.

In the following, 4 scenarios (S1, S2, S3 and S4) are described, assessing how plausible external changes will affect the electricity model and the importance of the ECHO thermal energy storage device. These scenarios will be analysed in more detail in Task 2.4. The Figures 47, 48 49 are intended to be schematic representations of the electrical behaviour in each scenario (hence no units are provided). They act as conceptual sketches to help visualise each of the scenarios.

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- **S1: Rising outdoor temperatures affecting cooling demand due to climate change:** In this scenario (example in Figure 47), the impact of the increase of the outdoor temperature on cooling demand due to climate change will be analysed. Rising temperatures are expected to alter cooling energy consumption patterns, which could lead to a significant increase in cooling demand (and thus its associated electricity consumption). Both increased consumption in existing cooling installations and an increase in new installations. How these changes affect the electricity network will be assessed, especially in terms of possible network overloads. The role of thermal energy storage (TES) device and the flexibility market will be assessed to determine how they can avoid the costs associated with increasing grid capacity.

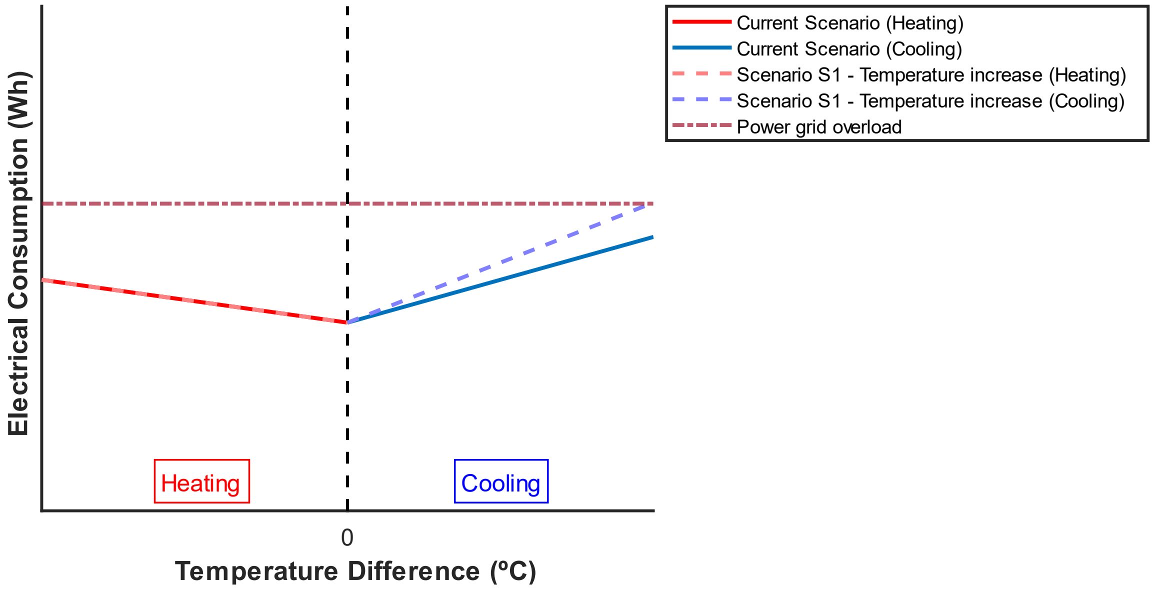

Figure 47. Scenario 1: Rising outdoor temperatures affecting cooling demand due to climate change

- **S2: Increase of Electricity Consumption Due to Higher Penetration and Implementation of Heat Pumps for heating and cooling:** This scenario (example in Figure 48) examines the effects of increased electricity consumption resulting from a higher penetration and implementation of heat pumps (HP) for cooling and cooling purposes. As more buildings adopt HPs, the electrical demand for heating and cooling will rise, impacting the grid's load. The potential for grid overload and explore how TES devices and the flexibility market can help preventing the need for costly grid capacity upgrades will be studied.

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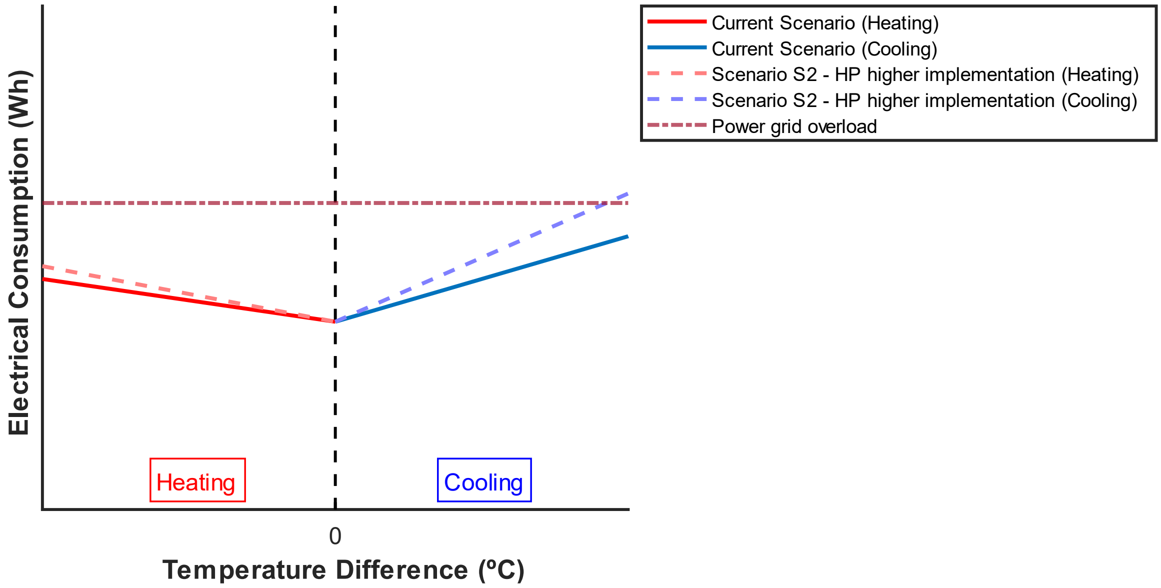

Figure 48. Scenario 2: Increase of Electricity Consumption Due to Higher Penetration and Implementation of Heat Pumps

- **S3: Increase of Electricity Consumption Due to Substitution of Gas Boilers for Heating with Heat Pumps (Electrification of H&C Systems):** In this scenario (example in Figure 49), the increase in electricity consumption due to the substitution of gas boilers with heat pumps for heating is assessed (and their use for cooling purposes as well), a process known as the electrification of H&C systems. The shift to electric heating systems is expected to significantly raise the electrical load on the grid. Impact on grid overload and examine how TES devices and the flexibility market can alleviate the associated costs by optimizing the demand and enhancing grid stability is analysed.

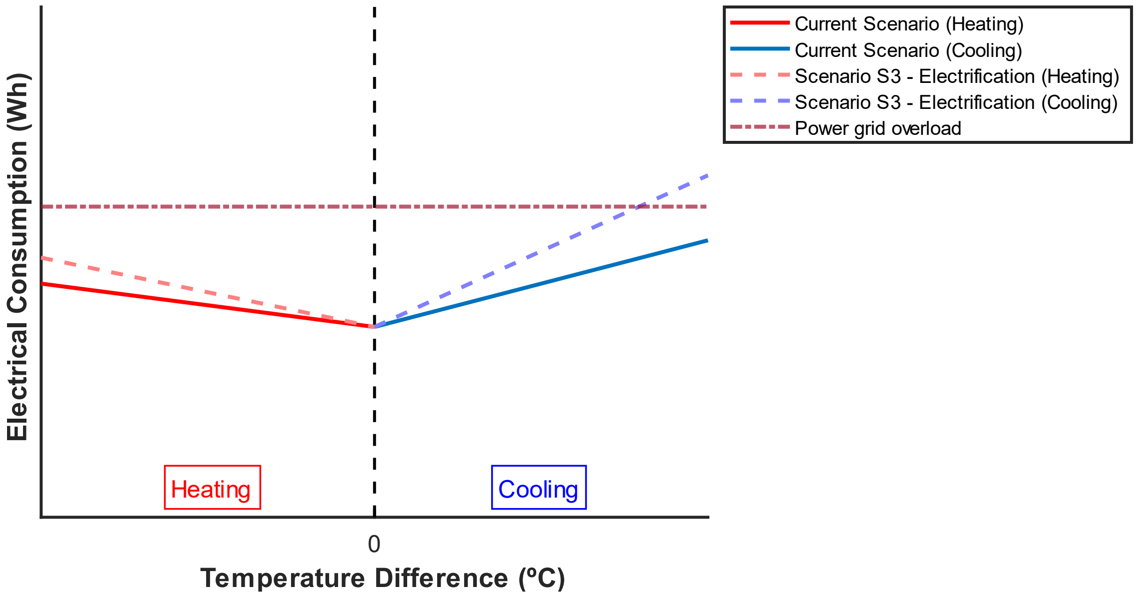

Figure 49. Scenario 3: Increase of Electricity Consumption Due to Substitution of Gas Boilers for Heating with Heat Pumps

- **S4: Maximization of Renewable Energy Consumption:** This scenario focuses on maximising renewable energy consumption. By increasing thermal consumption when renewable energy sources are available, it aims to boost the share of renewables in the local energy mix and decrease carbon

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emissions. It will assess how the increased availability of renewable energy affects the electricity grid, and explore the potential benefits of TES devices.

These scenarios will be specifically executed and analysed in the city of Crevillente during Task T2.4. The primary objective is to assess the impact these scenarios have on the electrical grid, particularly focusing on how the increased electrical load for climate control can lead to grid overload. The analysis will also explore how TES devices and the flexibility market can prevent the costs associated with increasing grid capacity, ensuring a stable and efficient energy system.

5.1 Spatial application

The spatial analysis will be conducted within the T2.4 *ECHOTSS spatial analysis: maximizing the impact of ECHO TES system implementation* activities. As the GA establish, T2.4 aims to simulate ECHOTSS scenarios in two target cities with different climate and energetic profiles to obtain conclusions about the optimal configuration of individual systems, control and aggregated behavior, influence of regulatory and market conditions, etc. For this purpose, Task 2.4 is working on the definition of a GIS-conducted method that allows to identify candidate areas to install ECHO TES in two different Spanish cities (Crevillente and Bilbao) with different climate conditions.

The intention of this section is to provide an overview of T2.4 approach and how it relates to the results that are being obtained in T2.3. Complete information will be provided in D2.4 *ECHO TSS implementation report in two realistic urban cases and final impact assessment of its deployment*, expected for August 2025.

In order to facilitate the understanding of the approach, six steps process has been defined to organize the main aspects that will be considered:

1. **Identification of ECHOTES implementation drivers and barriers**: technical and economical (from T2.3), spatial, legal, social, and environmental. Figure 50 provides examples of potential drivers and barriers per field.

Figure 50 Examples of potential drivers and barriers to ECHO TES implementation.

2. **Analytical spatial components definition**. Firstly, the prioritization criteria is defined according to the potential barriers and drivers identified in the previous step. Prioritization criteria is the criteria that will be considered in the GIS overlay analysis to determine the suitability of a location to implement ECHO TES. For this purpose, and extensive survey was conducted among project partners, obtaining as a result the preliminary approach that is reflected in Figure 51. Secondly, the analytical spatial components that will allow to introduce in the geoprocessing analysis the prioritization

criteria are defined. This will depend on data availability as well. Currently the technical team is working on this, as it is site-specific.

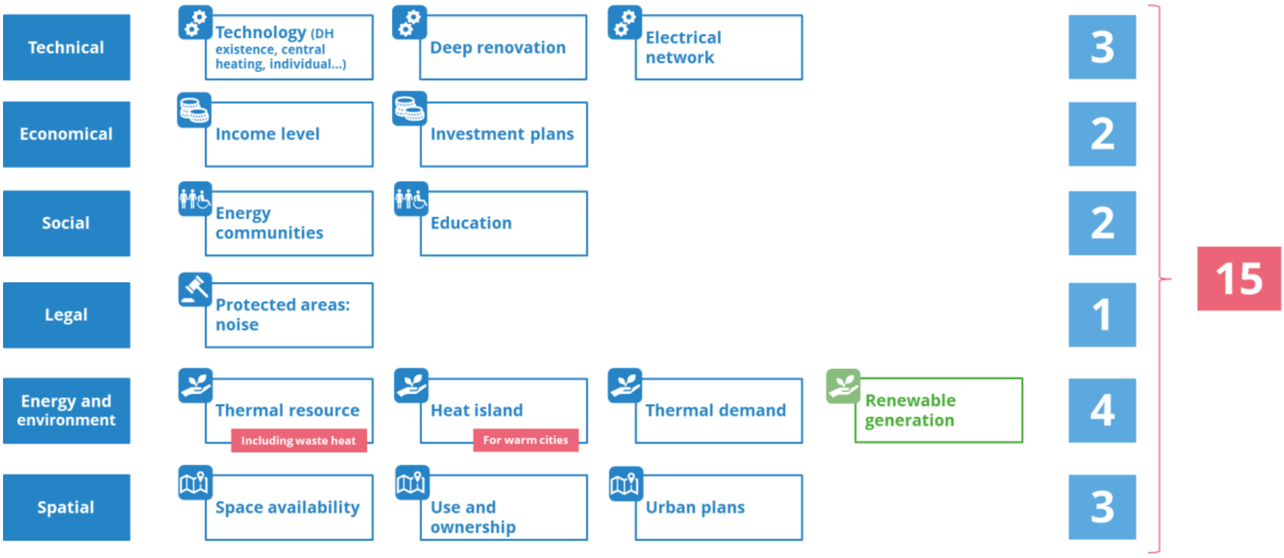

Figure 51 Prioritization criteria for ECHO TES implementation (draft).

3. **Case studies definition and analysis**. The approach presented in Figure 51 must be adapted to the local conditions of the case studies. Technical partners are currently working on this phase. Data from Crevillente and Bilbao has been collected and it is being processes to be able to conduct the proposed 4 steps method that will have as a result the identification of candidate areas to implement ECHO TES in Crevillente and Bilbao:

Figure 52 Methodological steps to identify candidate areas to install ECHO TES in specific case study.

3.1. Key criteria selection. The final selection of the prioritization criteria and the analytical components adapted to the case study conditions will be done in this step.

3.2. Cost benefit definition. This step is referred to the characterization of the criteria according to:

- Benefit: the criteria has a positive influence. For example, the income level: when higher, more probability of technology implementation.
- Cost: the criteria has a negative influence. For example, the protected areas: probably ECHO TES can't to be installed in this type of spaces.

3.3. Pairs comparison. In this step the criteria is characterized according to their relative importance. This step is conducted by experts.

3.4. TOPSIS-AHP georeferenced. This step is referred to the definition of the most suitable combination (PIS: Positive Ideal Solution) and less suitable combination (NIS: Negative Ideal Solution). Afterwards, the distance of a building to both combinations is calculated. As a result, a value is given to each solution or building according to both distances (PIS and NIS), providing the information regarding the candidate areas to implement ECHO TES.

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4. **Scenarios definition**. Once the case studies are characterized according to their suitability to implement ECHO TES, different technology penetration levels will be defined in accordance with T2.3 results.
5. **Scenarios assessment**. The analysis of the scenarios defined in previous step will be supported in GIS. The assessment aims to maximize the contribution of ECHO TES to achieve energy transition goals at local level. In collaboration with WP7 activities, indicators like the primary energy, the global warming potential, the investment and the payback time will be calculated.
6. **Conclusions.** The conclusions drawn in T2.4 will serve as inputs to T2.5 *Results analysis* and WP7 Environmental and cost assessment.

Urban population is growing fast. According to data from the world bank[8], the urban population in Spain (where the two cities of the case studies are located) is suffering a continuous growing trend. For example, in 2022 represented the 81% of the total population, whilst 20 years before it represented the 77%. The Spanish National Bank considers that this growth is even higher and reflects in his 2020[9] study that the fraction of the Spanish population living in urban areas has raised from 65% to over 87% between 1950 and 2018.

This growing trend must be considered into the decision-making processes of urban planning and in the conversion of the cities into climate neutral. In this sense, cities must deal with the decarbonization of their energy systems. Moreover, they must ensure the supply of a growing energy demand. Thermal storage can play a significant role in the decarbonization of the heating, cooling and domestic hot water (DHW) systems, providing flexibility, avoiding the intermittency of the renewable energy sources and helping in maximizing their use.

6 Conclusions

In this deliverable "D2.3 – ECHO TSS agent-based simulation implementation final report", the theoretical foundations and the methodological framework have been established to assess the potential impact of including ECHO thermal energy storage device combined with smart control implementation. This approach aims to achieve a critical mass of demand, facilitating the shift of the local energy mix towards a greater inclusion of local renewable electricity (RES) and the potential of flexibility to mitigate electrical grid overload. In Task T2.4, this methodology will be applied to verify the specific results in the city of Crevillente, based on the proposed scenarios.

On the thermal side, the ECHO Clima module within the ECHO TSS paradigm was developed with the objective of providing a predictive tool for the thermal part of electricity consumption based on the EUReCA model, and we have demonstrated the feasibility and possibilities of the scheme using data provided by ENERCOOP in the Crevillente pilot.

The results show not only the feasibility of the model but also highlight important conclusions from the observation of the data to support the demand flexibility schemes developed by ECHO TSS.

First, there is a clear elasticity of cooling demand with respect to factors such as external temperature and the penetration rate of cooling equipment in the district or group of buildings analyzed. The data from the selected electrical substations indicate that demand increases between 54% and 110% for each degree of positive temperature difference with respect to the so-called neutral temperature, as explained in the previous sections.

On the heating side, the demand exhibits a completely different behavior, being relatively insensitive to negative temperature differences.

8 https://datos.bancomundial.org/indicator/SP.URB.TOTL.IN.ZS?end=2022&locations=ES&start=1960
9 https://repositorio.bde.es/bitstream/123456789/14123/4/do2027.pdf

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This is due to the importance of the gas vector in the configuration of energy consumption.

In Task T2.4 of ECHO, we further develop these concepts to obtain a holistic consumption prediction system that can be fed into the ECHO Grid tool discussed below. ECHO GRID is a physically based model of the grid where the installation of ECHO-TSS devices will have a specific impact from a technical point of view. This model was implemented using the open-source software OpenDSS and it has been programmed in Python, which makes it versatile because additional modules can be added if necessary in a very flexible manner.

This model allows performing power flow analysis to determine the working points of the system in steady state for different time horizons. In this case, the model is prepared to calculate the status of the system (which means determining the complex voltage and power in all the busses of the grid, as well as the power flow throughout the different power lines and transformers) on an hourly basis and for different periods of time, from days to weeks, months, or whole years.

ECHO GRID, like the thermal module, was customized to simulate Enercoop's electricity grid in Crevillente, Spain. As a result, the tool precisely imitates the behavior of the distribution system, delivering accurate results. In section 3.3, real measurements supplied by the distribution company were used to validate the model, resulting in less than a 10% disparity between real and simulated values in most cases.

Four scenarios simulating the ECHO-TSS impact on the grid were compared to a base case of the grid during typical summer and winter days. Specific transformation centers would experience an enhanced load as a result of predicted temperature changes and/or an augmented number of electrical appliances for thermal comfort. In simulations with extreme load conditions, installing ECHO-TSS devices in 72% of residential consumers resulted in a satisfactory solution, allowing load increments up to 75%, given that these consumers provided energy storage services. ECHO-TSS demonstrated its utility in addressing network issues from a technical standpoint.

Finally, the economic profit of this service for device owners relies heavily on market mechanisms allowing for flexible trading based on proven strategies. A robust platform like ECHO CLOUD – extensively described in this report - is thus essential for carrying out aggregation activities, designing attractive contract models, and providing adequate price signals for flexibility providers.

7 References

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8 Annex

id	name	type	U-value [W/(m2 K)]	Weight class	Boundary (only vdi)
63	tilted roof with cavity between rafters	Roof	2.6	Light	Asim
64	timber frame	ExtWall	2	Light	Asim
65	natural stone floor on soil	GroundFloor	2.9	Light	Asim
66	wooden beam ceiling	GroundFloor	0.88	Light	Asim
67	ith clay/straw filling betv	Roof	1.3	Light	Asim
68	brickwork	ExtWall	1.7	Light	Asim
69	beam ceiling with visibl	Roof	0.77	Light	Asim
70	Roof	Roof	0.44	Medium	Asim
71	GroundFloor	GroundFloor	0.44	Medium	Asim
72	IntCeiling	IntCeiling	0.75	Light	Asim
73	ExtWall	ExtWall	0.56	Medium	Asim
74	IntWall	IntWall	0.75	Light	Asim
76	Roof	Roof	0.65	Medium	Asim
77	GroundFloor	GroundFloor	1	Medium	Asim
78	IntCeiling	IntCeiling	1.55	Light	Asim
79	ExtWall	ExtWall	1	Medium	Asim
80	IntWall	IntWall	1.2	Light	Asim
82	Roof	Roof	1.4	Medium	Asim
83	GroundFloor	GroundFloor	1.13	Medium	Asim
84	IntCeiling	IntCeiling	2	Light	Asim
85	ExtWall	ExtWall	1.8	Heavy	Asim
86	IntWall	IntWall	1.4	Light	Asim
88	Roof	Roof	1.92	Medium	Asim
89	GroundFloor	GroundFloor	1.31	Medium	Asim
90	IntCeiling	IntCeiling	2.3	Light	Asim
91	ExtWall	ExtWall	2.08	Heavy	Asim
92	IntWall	IntWall	2.3	Light	Asim
94	Roof	Roof	2	Medium	Asim
95	GroundFloor	GroundFloor	1	Medium	Asim
96	IntCeiling	IntCeiling	2.3	Light	Asim
97	ExtWall	ExtWall	2.5	Heavy	Asim
98	IntWall	IntWall	2.3	Light	Asim
100	Roof	Roof	3.08	Medium	Asim
101	GroundFloor	GroundFloor	1.13	Medium	Asim
102	IntCeiling	IntCeiling	2.3	Light	Asim
103	ExtWall	ExtWall	2.56	Heavy	Asim
104	IntWall	IntWall	2.3	Light	Asim
106	Roof	Roof	4.17	Medium	Asim
107	GroundFloor	GroundFloor	1	Medium	Asim
108	IntCeiling	IntCeiling	2.3	Light	Asim
109	ExtWall	ExtWall	2.56	Heavy	Asim
110	IntWall	IntWall	2.3	Light	Asim

Envelopes | Opaque_types | Constructions | Materials | Windows

Figure 53 Construction section of the envelopes file.

id	name	U [W/(m²K)]	Solar_Heat_Gain_Coef [-]	visible_transmittance [-]	frame_factor [-]	shading_coef_int [-]	shading_coef_ext [-]
75	Window 1. Low-e double glazin	2.3	0.27	0.64	0	1	0.9
81	Window 2	3.2	0.5	0.7	0	1	0.9
87	Window 3. Double glazing, air f	3.7	0.7	0.79	0	1	0.9
93	Window 4	4	0.75	0.79	0	1	0.9
99	Window 5	4.59	0.8	0.8	0	1	0.9
105	Window 6. Single glazing, wooc	4.9	0.82	0.85	0	1	0.9
111	Window 7. Single glazing, wooc	4.9	0.82	0.85	0	1	0.9

Envelopes | Opaque_types | Constructions | Materials | Windows

Figure 54 Windows section of the envelopes file.

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Table 10 Occupancy, equipment, and lighting schedules for a residential building.

h	Energy calculations					
	Working days			Weekends		
	Occupancy	Equipment	Lighting	Occupancy	Equipment	Lighting
1	1	0.5	0	1	0.5	0
2	1	0.5	0	1	0.5	0
3	1	0.5	0	1	0.5	0
4	1	0.5	0	1	0.5	0
5	1	0.5	0	1	0.5	0
6	1	0.5	0	1	0.5	0
7	0.5	0.5	0.15	0.8	0.5	0.15
8	0.5	0.7	0.15	0.8	0.7	0.15
9	0.5	0.7	0.15	0.8	0.7	0.15
10	0.1	0.5	0.15	0.8	0.5	0.15
11	0.1	0.5	0.05	0.8	0.5	0.05
12	0.1	0.6	0.05	0.8	0.6	0.05
13	0.1	0.6	0.05	0.8	0.6	0.05
14	0.2	0.6	0.05	0.8	0.6	0.05
15	0.2	0.6	0.05	0.8	0.6	0.05
16	0.2	0.5	0.05	0.8	0.5	0.05
17	0.5	0.5	0.2	0.8	0.5	0.2
18	0.5	0.7	0.2	0.8	0.7	0.2
19	0.5	0.7	0.2	0.8	0.7	0.2

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20	0.8	0.8	0.2	0.8	0.8	0.2
21	0.8	0.8	0.2	0.8	0.8	0.2
22	0.8	0.8	0.2	0.8	0.8	0.2
23	1	0.6	0.15	1	0.6	0.15
24	1	0.6	0.15	1	0.6	0.15

Table 11 Occupancy, equipment, and lighting schedules for a commercial and service building.

h	Energy calculations					
	Working days			Weekends		
	Occupancy	Equipment	Lighting	Occupancy	Equipment	Lighting
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0.1	0.1	0.1	0.1	0.1	0.1
10	0.3	0.3	0.3	0.3	0.3	0.3
11	0.3	0.3	0.3	0.6	0.6	0.6
12	0.7	0.7	0.7	0.9	0.9	0.9

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13	0.6	0.6	0.6	1	1	1
14	0.5	0.5	0.5	0.9	0.9	0.9
15	0.6	0.6	0.6	0.7	0.7	0.7
16	0.6	0.6	0.6	0.5	0.5	0.5
17	0.9	0.9	0.9	0.3	0.3	0.3
18	0.9	0.9	0.9	0.3	0.3	0.3
19	1	1	1	0.45	0.45	0.45
20	0.9	0.9	0.9	0.45	0.45	0.45
21	0.7	0.7	0.7	0.45	0.45	0.45
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

Table 12 Occupancy, equipment, and lighting schedules for an industrial building.

h	Energy calculations					
	Working days			Weekends		
	Occupancy	Equipment	Lighting	Occupancy	Equipment	Lighting
1	1.5	5	0	0	0	0
2	1.5	5	0	0	0	0
3	1.5	5	0	0	0	0
4	1.5	5	0	0	0	0
5	1.5	5	0	0	0	0

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6	1.5	5	0	0	0	0
7	0.75	5	0.105	0	0	0
8	0.75	7	0.105	0	0	0
9	0.75	7	0.105	0	0	0
10	0.15	5	0.105	0	0	0
11	0.15	5	0.035	0	0	0
12	0.15	6	0.035	0	0	0
13	0.15	6	0.035	0	0	0
14	0.3	6	0.035	0	0	0
15	0.3	6	0.035	0	0	0
16	0.3	5	0.035	0	0	0
17	0.75	5	0.14	0	0	0
18	0.75	7	0.5	0	0	0
19	0.75	7	0.14	0	0	0
20	1.2	8	0.14	0	0	0
21	1.2	8	0.14	0	0	0
22	1.2	8	0.14	0	0	0
23	1.5	6	0.105	0	0	0
24	1.5	6	0.105	0	0	0

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Table 13 Occupancy, equipment, and lighting schedules for an office building.

h	Energy calculations					
	Working days			Weekends		
	Occupancy	Equipment	Lighting	Occupancy	Equipment	Lighting
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0.2	0.2	0.2	0	0	0
9	0.6	0.6	0.6	0	0	0
10	0.6	0.6	0.6	0	0	0
11	0.7	0.7	0.7	0	0	0
12	0.7	0.7	0.7	0	0	0
13	0.4	0.4	0.4	0	0	0
14	0.6	0.6	0.6	0	0	0
15	0.7	0.7	0.7	0	0	0
16	0.7	0.7	0.7	0	0	0
17	0.6	0.6	0.6	0	0	0
18	0.2	0.2	0.2	0	0	0

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19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

Table 14 Available EUReCA heating and cooling systems.

Available heating systems	IdealLoad
	CondensingBoiler
	TraditionalBoiler
	Traditional Gas Boiler, Centralized, Low Temp Radiator
	Traditional Gas Boiler, Single, Low Temp Radiator
	Traditional Gas Boiler, Centralized, High Temp Radiator
	Traditional Gas Boiler, Single, High Temp Radiator
	Traditional Gas Boiler, Centralized, Fan coil
	Traditional Gas Boiler, Single, Fan coil
	Traditional Gas Boiler, Centralized, Radiant surface
	Traditional Gas Boiler, Single, Radiant surface
	Condensing Gas Boiler, Centralized, Low Temp Radiator
	Condensing Gas Boiler, Single, Low Temp Radiator
	Condensing Gas Boiler, Centralized, High Temp Radiator
	Condensing Gas Boiler, Centralized, Single Temp Radiator
	Condensing Gas Boiler, Centralized, Fan coil
	Condensing Gas Boiler, Single, Fan coil
	Condensing Gas Boiler, Centralized, Radiant surface
	Condensing Gas Boiler, Single, Radiant surface
	Oil Boiler, Centralized, High Temp Radiator
	Oil Boiler, Single, High Temp Radiator
	Stove
	A-W Heat Pump, Centralized, Low Temp Radiator
	A-W Heat Pump, Single, Low Temp Radiator
	A-W Heat Pump, Centralized, Fan coil
	A-W Heat Pump, Single, Fan coil

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	A-W Heat Pump, Centralized, Radiant surface
	A-W Heat Pump, Single, Radiant surface
	Electrical Heater
Available cooling systems	IdealLoad
	SplitAirCooler
	ChillerAirtoWater
	SplitAirConditioner
	A-A split
	A-W chiller, Centralized, Fan coil
	A-W chiller, Centralized, Radiant surface
	A-W chiller, Single, Fan coil
	A-W chiller, Single, Radiant surface

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